VOLUME 29 ISSUE 4 DECEMBER 2014

ISSN: 1742-1705

CABI BIOSCIENCES GHAM LIBRARY 11 NOV 2014

Renewable Agriculture and Food Systems

journals.cambridge.org/raf

CAMBRIDGE UNIVERSITY PRESS

Renewable Agriculture and Food Systems

Editor-in-Chief
Rick Welsh, Professor of Food Studies, Dept. of Public Health, Food Studies and Nutrition, David B. Falk College of Sport and Human Dynamics, Syracuse University, Syracuse, NY
Email: rafjournal@cambridge.org

Assistant Editor-in-Chief
Lydia Oberholtzer, Pennsylvania State University, USA
Email: lso3@psu.edu

Forum Editors
Virginia Jin, United States Department of Agriculture – Agricultural, Research Service, Nebraska, USA
Fred Kirschenmann, Leopold Ctr. For Sustainable Ag., Iowa State University, Ames, USA.
Email: leopold1@iastate.edu

Associate Editors
Randy Anderson, USDA, Agricultural Research Service (ARS), USA
Shabtai Bittman, Agriculture and Agri-Food, Canada
Stefano Canali, CRA-RPS, Italy
Kathleen Delate, Iowa State University, USA
Carloyn Dimitri, New York University, USA
Leslie Duram, Southern Illinois University, USA
Charles A. Francis, University of Nebraska, USA
Alan Franzluebbers, USDA-ARS, Georgia, USA
Amy Guptil, State University of New York, USA
Niels Halberg, ICROFS, Denmark
Clare Hinrichs, The Pennsylvania State University, USA
Gilles Lemaire, INRA, France
Don Lotter, St. John's University of Tanzania, Tanzania
Richard Mulvaney, University of Illinois at Urbana-Champaign, USA
Daniel Neuhoff, Bonn University, Germany
Marica Ostrom, Washington State University, USA
Elizabeth P. Ransom, University of Richmond, USA
Shane Rogers, Clarkson University, USA
Margaret Roper, CSIRO Plant Industry, Australia
David Schimmelpfennig, USDA Economic Research Service (ERS), USA
Theresa Selfa, State University of New York (SUNY), USA
Mickey Swisher, University of Florida, USA
Ilkden Talay, Ankara University, Turkey
Santiago Veron, Universidad de Bueno Aires, Argentina
Raymond R. Weil, University of Maryland, USA
Sam Wortman, University of Illinois at Urbana-Champaign, USA

Submission of Manuscripts
Manuscripts should be submitted via our online manuscript submission and tracking site, **www.edmgr.com/rafs**.
Full instructions for electronic submission are available directly from this site and from journals.cambridge.org/raf.
To facilitate rapid reviewing, communications for peer review will be electronic and authors will need to supply a current e-mail address when registering to use the systems.

Full Notes for Authors are available from:
journals.cambridge.org/raf

Subscriptions
Renewable Agriculture and Food Systems (ISSN 1742-1705) is published four times a year in March, June, September and December. The subscription price for institutions of Volume 29 (2014) which includes electronic access and delivery by air is £307 (US $540 in the USA, Canada and Mexico); the electronic only price for institutions is £212 (US $379 in the USA, Canada and Mexico). Single parts are £79.20 (US $137.77 in the USA, Canada and Mexico), plus postage.

Orders, which must be accompanied by payment, may be sent to a bookseller, subscription agent or direct to the publisher: Cambridge University Press, The Edinburgh Building, Shaftesbury Road, Cambridge CB2 8RU, UK; or in the USA, Canada and Mexico: Cambridge University Press, Journals Fulfillment Department, 100 Brook Hill Drive, West Nuack, New York, 10994-2133. EU subscribers (outside the UK) who are not registered for VAT should add VAT at their country's rate. VAT registered subscribers should provide their VAT registration number.

Japanese prices for institutions are available from Kinokuniya Company Ltd, P. O. Box 55, Chitose, Tokyo 156, Japan.

Copies of the journal for subscribers in the USA, Canada and Mexico are sent by air to New York to arrive with minimum delay. Periodicals postage paid at New York and at additional mailing offices. Postmaster: send address changes in the USA, Canada and Mexico to: *Renewable Agriculture and Food Systems*, Cambridge University Press, 100 Brook Hill Drive, West Nyack, New York 10994-2133. Claims for missing issues should be made immediately on receipt of the subsequent issue.

Advertising
Advertising queries for all parts of the world except the USA, Canada and Mexico to the Journals Advertising Co-ordinator: Rebecca Curtis, ad_sales@cambridge.org
Address enquiries in the USA, Mexico and Canada only to: journals_advertising@cup.org

Copying
This journal is registered with the Copyright Clearance Centre, 222 Rosewood Drive, Danvers, MA 01923, USA. Organizations in the USA who are also registered with C. C. C. may therefore copy material (beyond the limits permitted by sections 107 and 108 of U.S. Copyright law) subject to promotional or commercial purposes. Code 1742-1705/2014 $16.00. *ISI Tear Sheet Service*, 3501 Market Street, Philadelphia, PA 19104, USA is authorized to supply single copies of separate articles for private use only. Organizations authorized by the Copyright Licensing Agency may also copy material subject to the usual conditions. *For all other use*, permission should be sought from Cambridge or the American Branch of Cambridge University Press.

Renewable Agriculture and Food Systems is abstracted/indexed in Academic Search FullTEXT, AGRICOLA (Bibliography of Agriculture), AGRIS, Biological and Agricultural Index, CAB ABSTRACTS, Dietary Supplements (IDIS) Database, Environment Abstracts, Environmental Periodicals Bibliography, First Search (OCLC), Sociological Abstracts, Social Planning/Policy & Developmental Abstracts, Uncover

Internet Access
The online edition is available at: journals.cambridge.org/raf with free table of contents alerts (upon registration).

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Shaftesbury Road, Cambridge CB2 8RU, UK
32 Avenue of the Americas, New York, NY 10013-2473, USA
477 Williamstown Road, Port Melbourne VIC 3207, Australia

This journal issue has been printed on FSC-certified paper and cover board. FSC is an independent, non-governmental, not-for-profit organization established to promote the responsible management of the world's forests. Please see www.fsc.org for information.
Printed by Latimer Trend, Plymouth, UK.

"Sustaining Earth and its People"

Scales image: Design, George Eisele, Lincoln, NE; artwork, Pat Scullion, ASA/CSSA/SSSA, Madison, WI, USA

Renewable Agriculture and Food Systems: 29(4); 291–309 doi:10.1017/S174217051300015X

Certified quality systems and farming practices in olive growing: The case of integrated production in Andalusia

Ascensión Hinojosa-Rodríguez[1], Carlos Parra-López[1]*, Carmen Carmona-Torres[1], Samir Sayadi[1] and Rosa Gallardo-Cobos[2]

[1]Department of Agricultural Economics and Sociology, Andalusian Institute of Agricultural Research and Training (IFAPA), P.O. Box 2027–18080 Granada, Spain
[2]Department of Agricultural Economics, Sociology and Policy. University of Cordoba, P.O. Box 3048–14080 Cordoba, Spain
*Corresponding author: carlos.parra@juntadeandalucia.es

Accepted 2 April 2013; First published online 29 May 2013 **Research Paper**

Abstract

The competitiveness of the olive agrofood sector depends heavily on its ability to adapt to the current scenario of increasingly internationalized interchanges, segmentation of markets, differentiation of consumption behaviors, and changing public support for agriculture. Quality differentiation and certification through a Certified Quality System (CQS) ensure the quality of products and services beyond mandatory levels and generate a competitive advantage for certified firms. In the Andalusian olive-growing sector, the largest in the world, integrated production (IP) plays an important role. IP certifies a higher quality of the product and production process by guaranteeing the implementation of farming practices that are hypothetically more sustainable, environmentally friendly, profitable, fair for farmers, and healthy for consumers. This paper investigates the underlying factors that have conditioned the diffusion of IP and tries to confirm the differential and higher quality provided by this CQS. A survey of 400 farmers from the main olive-growing provinces of Andalusia was carried out in 2010/2011 on the basis of face-to-face interviews following a structured questionnaire. The results corroborate low levels of knowledge and adoption of most of the available CQSs in the sector. They also confirm the higher quality of IP olive products and processes since farmers adopting this CQS are implementing better farming practices from an agronomic, environmental and economic point of view. The better practices are especially those related to soil management, irrigation, phytosanitation and harvesting. Otherwise, olive farmers in general seem to be entrenched in a relatively closed information system where 'contagion' of information among themselves and from close sources is the main diffusion driver, with no significant influence from external sources such as public and private R&D institutions. Moreover, a lack of orientation of farmers toward satisfying customers' requirements when innovating was detected. Strengthening the diffusion of IP would require bringing information closer to farmers in an accessible manner. The work of R&D institutions is essential in this context. Special emphasis should be placed on the medium- to long-term economic benefits and improved competitiveness associated with IP, these being the main concerns of farmers. Improved access to credit would also probably encourage its adoption. It is also necessary to convince farmers of the environmental and social benefits associated with IP. Reinforcing public policies promoting the professionalization of the sector and training in marketing are also necessary measures.

Key words: olive growing, Certified Quality Systems, integrated production, good agricultural practices, adoption factors, innovation

Introduction

An increase in the segmentation of markets and in the differentiation of consumption behaviors is a key factor for the future of the world olive oil market, which will lead to a major quality-based product diversification and differentiation of marketing strategies. Increasing consumer demand is anticipated for olive oils that are differentiated on the basis of product and process quality attributes, such as those linked to origin or to alternative production techniques such as organic agriculture[1]. The globalization of the world economy and the expansion of

© Cambridge University Press 2013

international trade have led to rapid processes of quality internationalization as a crucial element of companies' competitiveness[2]. Achieving, enhancing and sustaining competitiveness is dependent on delivering superior quality products/services to consumers[3]. The image of quality olive oils is currently taking on increasingly more positive connotations among consumers in developed countries, as well as in the upper middle classes of society in developing countries[4]. In this context, producing olives and olive oil of differentiated quality can result in a competitive advantage for olive farmers and industries. Given the globalization of markets and the increasing distances between producers and potential consumers, it is difficult for buyers to observe the qualifications of suppliers[5]. Certification through Certified Quality Systems (CQSs) may reduce information asymmetries in supply chains and thereby generate a competitive advantage for certified firms[2,5] by ensuring the quality of products and services and eliminating technical barriers in trade[2]. Moreover, it provides further incentives for the seller to provide high-quality goods[6] to intermediate customers and final consumers. CQSs are voluntary and usually require an organization to demonstrate that it achieves a standard of quality beyond conventional and mandatory levels by employing a specific set of management practices. Usually, these practices must be verified by a third party auditor[5]. CQSs can be seen as institutions in the sense that they are rules that facilitate coordination between people by helping them form expectations that each person can reasonably hold in dealing with others[7]. Quality is a multidimensional and complex concept that can be interpreted from diverse perspectives[8], and the various different CQSs can have different focuses in terms of the quality they guarantee to consumers or customers[9–11]: food security, organoleptic properties, nutritional value, raw material treatment, origin, sustainability, environmental care, health of producers, fair trade, animal welfare, etc. Although certification of quality through the implementation of a CQS is a costly process, its adoption is usually aimed at minimizing the cost in relation to profit[12]. The set of management practices associated with a CQS may represent a form of technological innovation for farmers, if we understand innovation in a broad sense as an idea, practice or object perceived of as new by an individual[13].

Spain is the world-leading olive (*Olea europaea*, spp.) growing country both in terms of surface area and production: 2.4 million ha and 6.2 million tons of olives per year in the period 2005–2010, which represents 24.9% of the world's olive surface area and 35.8% of world production[14]. Most of the Spanish production (93.0% in 2009)[15] goes to olive mills to produce mainly olive oil and the rest is processed as table olives. Spanish olive oil is mainly destined for exportation: 62.8% was exported in 2009[15], including both the final bottled product and the bull olive oil to be subsequently processed and bottled. Moreover, olive oil exportation is clearly increasing: while olive oil production increased by 3.2% per year in the period 1996–2009, exportation increased by 14.8% per year in the same period[15,16]. The main destinations of Spanish exports, according to the most recent data available (2009), were the rest of the EU-27 countries (74.8% of exports) and emerging markets such as USA and Australia (7.3 and 2.7%, respectively)[15]. The Spanish olive production sector consists primarily of a wide group of small/medium olive growers organized into olive oil cooperatives, which account for more than 70% of the olive oil produced, and a minority of private olive oil mills belonging to large farmers[4]. Andalusia, located in the south of Spain, is by far the country's most important olive-growing region. Andalusian olive cultivation represented 61.9% of the olive surface area and 84.3% of olive production in Spain in 2009[15]. In macroeconomic terms, olive growing provided 27.7% of Andalusian plant production in 2010[17], and generated 32% of the agricultural employment[18], this being the second largest agricultural sector in the region after the production of vegetables[17]. A large share of the olive groves of Andalusia is located in marginal areas and would incur financial losses if the EU subsidies were to disappear: specifically, 58.3% of farms and 61.5% of the olive area[19]. The Andalusian olive-producing sector faces a 'marketing problem' with regard to olive oil cooperatives, which draw together most of the olive producers and primary extraction industries and have a weak presence in the bottled olive oil market, thus losing a large share of the added value of the final product in favor of a few bottling industries and big distribution platforms[20]. A very small number of firms own the most valuable labels and control most of the olive oil sold in the largest markets[1]. Therefore, competitiveness through differentiation in the market and consumer value creation is a fundamental strategy for farmers to survive, especially for small/medium farmers, since they cannot compete with large-scale distribution whose marketing strategies are mainly based on price[21].

CQSs available for Andalusian olive growers include (1) EU, Spanish, and Andalusian public regulations, such as Protected Designation of Origin (PDO), organic and integrated agriculture; (2) International Standards (ISO) norms, such as 9001, 14001, 19011 and 22000; and (3) retailers' private protocols, such as GLOBALGAP, International Food Standard (IFS), and Nature's Choice, among others. Despite the wide range of potentially adoptable CQSs and the importance of a strategy of differentiated certified quality for the agents of the olive agrofood system, currently only a few CQSs are adopted. In the past few decades, certification of the product and processes in the Andalusian olive sector in particular and the agrofood system in general has relied almost exclusively on a few CQSs backed by public regulations; the adoption of privately financed quality schemes is token by comparison[22]. Two trends in quality certification can be distinguished: (1) certification of alternative

production systems associated with more sustainable and environmentally responsible practices that are profitable and fair for farmers and healthy for consumers, such as those promulgated by integrated production (IP) and organic agriculture; and (2) certification of the origin of the product through schemes such as the PDO. Among these relatively widespread CQSs, the one that stands out the most is IP.

IP is an alternative agricultural production system, which arose as a reaction against problems surrounding conventional chemical agriculture, related to the environment, food quality, sustainability and the survival of the rural world[23]. The origin of the concept of IP goes back to 1977 and was established as a result of a researchers' meeting in Switzerland, organized by the OILB/IOBC (Organisation Internationale de Lutte Biologique/International Organisation for Biological Control). This organization began its attempt to define the concept of IP in the 1960s, in response to the massive use of synthetic pesticides in agriculture. The scope of IP included and went further than the integrated pest management concept that previously appeared in Europe and the USA in the 1950s. The OILB/IOBC is the organization possessing the greatest experience and authority on the aspects of IP; since 1977, it has run a recognition service for regional plans and a commission on IP[24]. In Spain, as in other countries, the regulation of IP began at the regional level, first in Catalonia in 1993 and then in Andalusia in 1995 (Decree 215/1995) following the OILB/IOBC guidelines. Subsequently, in 2002, the first regulation of IP at the national level was established with Royal Decree 1201/2002. This regulation defines IP as farming systems for vegetable and fruit production, which make the maximum use of resources and production mechanisms and ensure long-term sustainable agriculture, introducing biological and chemical control methods and other techniques that reconcile the demands of society, environmental protection and agricultural productivity, as well as operations for the handling, packaging, processing and labeling of vegetable and fruit products included in the system. The main goal of defining IP principles and rules is to achieve high-quality production by means of an efficient use of production factors, taking into account sustainability criteria and environmental compliance[25]. This norm also established the general IP rules for farms and processing industries, distinguishing among mandatory, forbidden and recommended practices. In addition, the norm defines some crop-specific technical standards developed by an IP national commission, such as those referring to vegetables, citrus, garlic, cotton and sugar beet. Once the national regulations have been set, Spanish regions had to adapt their own regional regulations to them. IP olive growing in Andalusia is regulated by the Order of 15 April 2008 (BOJA num.83). This norm consists of two fundamental parts: agronomic practices (including mandatory, recommended and forbidden practices) and integrated control strategies[25]. Regulated agricultural practices are related to the soil, land preparation, tillage, and management of vegetation cover, planting, fertilizing, irrigation, pruning, integrated control and harvesting. Mandatory practices related to soil management are soil conservation practices to reduce soil erosion; with regard to fertilization, olive farmers have to do at least one foliar test per year, as well as a physical and chemical soil analysis in each farm; in terms of irrigation, they have to carry out a test on water quality every 2 years in an accredited laboratory, and flooding irrigation is forbidden; in pest control, wherever possible, they have to use biological rather than chemical control methods; with respect to harvesting, it is forbidden to mix olives taken from the trees and the ground and to transport them in bags. Otherwise, the control strategy is based on inspection, identification and treatment, mainly conducted through periodical visits from field technicians. At least one onsite check a year is performed on every farm. The specific regulations for agronomic practices and integrated control strategies must be changed when technological advances make it advisable[25]. IP is an upward trend in Andalusia (Fig. 1), representing 16.7% of the total olive area in 2009[26,27]. This is a relatively high adoption rate compared to other CQSs, which are just starting to be recognized by farmers.

Despite the relative success of the adoption of IP as a form of technological innovation, it is remarkable how few studies in the international literature deal with the diffusion of IP as a quality strategy in the agricultural sector in general and the Andalusian olive-growing sector in particular. In fact, the international literature on CQSs in the olive agrofood system can be classified into the following different categories, which makes the lack of IP studies patent: (1) PDO, as a quality differentiation strategy for olive producers[4,28,29–33], its consumer demand/acceptance[34–40] and its market[41,42]; (2) organic agriculture, its process of diffusion/adoption in the olive sector[43–46] and its multifunctional impacts[18,23,47,48] (3) ISO 9001, its adoption as a market strategy[29] and its influence on olive oil quality[49]; (4) quality, in general, as a market strategy for olive producers[28,21,50] and as an output associated with the adoption of certain good practices[51]; and (5) consumer demand for quality olive oil[52–54]. Among the scarce studies on IP, some indicate that the adoption of IP, similarly to other CQSs, increases the competitiveness of agriculture and allows farmers to access new markets[22]. Other authors argue that in the IP framework, quality is understood as a globally oriented concept to increase the sustainability and multifunctionality of agriculture rather than focusing solely on production and profitability[55]. Along the same lines, some previous studies compared the multifunctional impacts of IP and conventional olive growing in Andalusia, among other production systems, and demonstrated its better global performance, particularly, not only from an environmental perspective but also in terms of profitability[18,23,47].

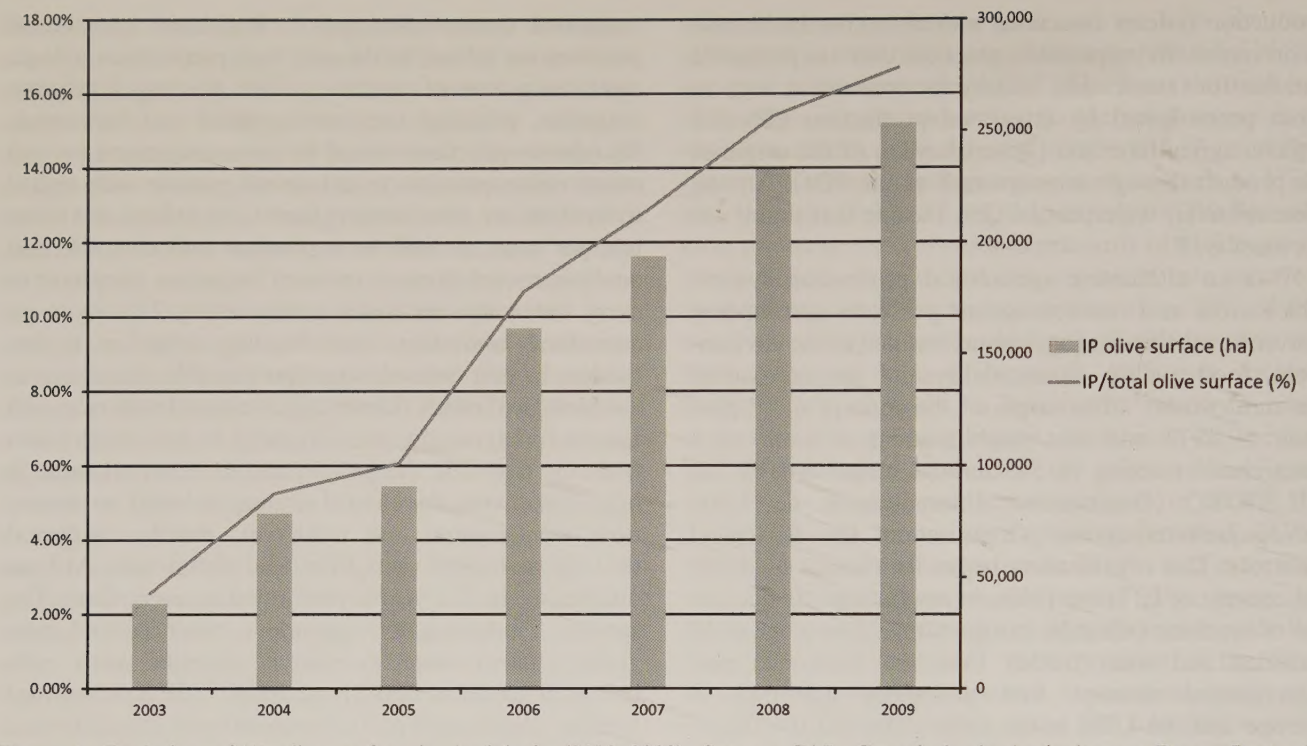


Figure 1. Evolution of IP olive surface in Andalusia (2003–2009). Source: CAP, Consejería de Agricultura y Pesca, Junta de Andalucía: http://www.cap.junta-andalucia.es/agriculturaypesca/portal/.

With this in mind, this research aims to contribute to filling this gap in the literature on the adoption of IP as a quality innovation in the agricultural sector in general and the olive-growing sector in particular. The specific objectives of this paper are as follows: (1) Describing and updating the general situation regarding the knowledge of, adoption of and intention to adopt a wide range of available CQSs in the olive-growing sector of Andalusia. (2) Comparing the farming practices really implemented by farmers adopting IP, as the most widely diffused CQS, to those of other farmers (non-IP), to check whether the adoption of IP is linked with a real change in farming practices and whether these practices are better from an agronomic, environmental and/or economic perspective. (3) Identifying the adoption factors of IP, i.e., the differential characteristics of farmers and farm structures that may be related with each other and serve to shed light on the adoption of the IP certification scheme. The final aim of the research is to investigate the interconnection between the characteristics of farmers and farms and the adoption of IP, the most widespread CQS in Andalusian olive growing, and between the adoption of IP and quality improvement, defining quality in terms of better farming practices for the environment, food quality and agricultural sustainability. Unveiling these links would help us to better understand the underlying mechanisms that have conditioned the diffusion/adoption process of IP in the region and provide a scientific basis for strengthening the diffusion of IP. This would allow the design of more effective public policies and private strategies to further stimulate the extension of IP and to steer the recognition and adoption of other CQSs in the Andalusian olive-growing sector.

Methodology

The research followed the methodological scheme summarized in Fig. 2. A survey of 400 farmers from the main olive-growing provinces of Andalusia was carried out from May 2010 to February 2011. The main provinces in terms of production and surface area devoted to olive oil are Jaen, Cordoba and Granada[56,57]. The stratification of the survey was proportional to the number of olive farmers in five major homogeneous olive-growing zones, previously defined, which include municipalities of similar importance for olive cultivation in terms of olive surface area over the total surface area. The survey was carried out on the basis of face-to-face interviews following a structured questionnaire that basically consists of four parts:

I CQSs known of and adopted: The CQSs analyzed include a wide range of available CQSs for olive farmers, including public regulations (PDO, organic, and IP), ISO norms (9001, 14001, 19011 and 22000), and private protocols. CQSs adopted are strictly those for which farmers are officially registered.

II Farming practices implemented: Reference is made to the practices of planting, soil management, irrigation, fertilization, phytosanitary treatments, harvesting,

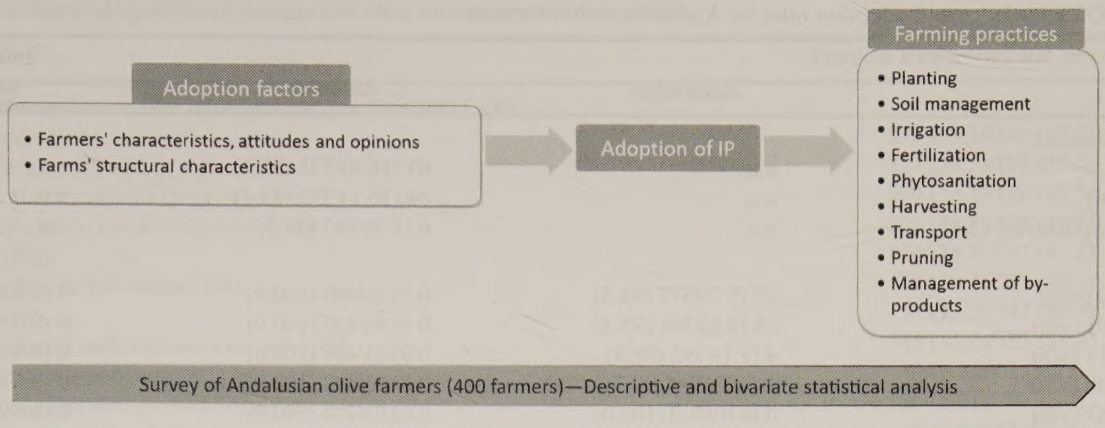


Figure 2. Methodological scheme of the research.

transport, pruning and management of by-products. Farming practices are variables, which are potentially related to the adoption of CQSs in general and IP in particular.

III Characteristics, attitudes and opinions of the olive farmers: These include agricultural training, sources of information on CQSs, objectives when producing, objectives when innovating, difficulties in innovating, and priorities in R&D, among others. All these are variables that can be related to the adoption of IP.

IV Structure of the olive farms: Questions related to farm area distribution, yield, type of labor force, destination of the product and slope of the land, among others. These can also be related to the adoption of IP.

The analyses carried out, which are in accordance with the objectives of the study and the results obtained, are as follows:

1. Knowledge and adoption of CQSs and attitudes toward R&D and innovation: A descriptive statistical analysis was carried out of the knowledge and degree of adoption of the CQS currently available to olive farmers. Additionally, some olive farmers' attitudes and opinions regarding R&D are described.
2. Farming practices associated with IP: On the basis of a bivariate statistical analysis of the agricultural practices implemented and the adoption of IP, we aimed to identify those practices that are significantly different due to the implementation of this certification scheme and also those practices that are implemented equally by IP and non-IP adopters. Bivariate statistical correlations are based on (1) corrected Yates χ^2 for contingent tables when degree of freedom (d.f.) = 1; (2) Pearson χ^2 for contingent tables when d.f. > 1; and (3) χ^2 for bivariate logit when proof for contingent tables is not statistically reliable. The aim is to identify significant differences between farmers and farms, which implement IP and those that do not.
3. Adoption factors of IP: A bivariate statistical analysis was conducted of the characteristics of olive farmers and farms and the adoption of IP. Bivariate statistical correlations are based on the same tests as for analysis 2 'Farming practices associated with IP'.

Results

Knowledge and adoption of CQSs and attitudes toward R&D and innovation

The most widely adopted quality systems among those studied are IP and PDO, with adoption rates of 16.8 and 16.1%, respectively (Table 1). Organic farming is only adopted by 1.5% of farmers. The remaining quality systems (ISO, GLOBALGAP, IFS and Nature's Choice) are not adopted at all and are known of by less than 6.0% of interviewees, almost none of whom had any intention of adopting them. These data confirm the generally low degree of knowledge and adoption of CQSs in the Andalusian olive-growing sector.

With respect to the attitudes and opinions of olive farmers regarding R&D and innovations (Table 2), on average—without differentiating between IP and non-IP farmers—they find out about new olive farming practices and CQSs mainly through other farmers (59.8% of interviewees), their own personal experience and practice (54.3%), agricultural associations (52.5%) and conferences, fairs, exhibitions, etc. (51.4%). This highlights the importance of personal contact with close sources that are internal to the agricultural system. Other sources of information, which can be considered external, such as customers, consultants, commercial laboratories, private R&D institutes, universities, public research organizations and technological centers are scarcely used; in fact, these are used by less than 10.0% of farmers in all cases. The Internet is cited by 13.2% of interviewees, representing a new means of communication to be exploited in the olive production sector. Otherwise, the main priority of olive farmers as producers is economic profit, since 94.9% of farmers attribute a great deal of importance to this factor. This high consideration for profit seems to determine their opinions on innovation in two ways. First, the objectives that an innovation must pursue, according to

Table 1. CQS knowledge and adoption rates by Andalusian olive farmers.

	Knowledge	Adoption	Intention of adopting
Public regulations			
IP (y/n)	n.a.	67 (16.8)/333 (83.2)	n.a.
PDO (y/n)	n.a.	64 (16.1)/335 (83.9)	n.a.
Organic agriculture (y/n)	n.a.	6 (1.5)/393 (98.5)	n.a.
ISO norms			
ISO 9000 (y/n)	23 (5.7)/377 (94.3)	0 (0.0)/400 (100.0)	3 (0.6)/397 (99.4)
ISO 14001 (y/n)	18 (4.6)/381 (95.4)	0 (0.0)/400 (100.0)	0 (0.0)/400 (100.0)
ISO 19011 (y/n)	4 (1.1)/395 (98.9)	0 (0.0)/400 (100.0)	0 (0.0)/400 (100.0)
ISO 22000 (y/n)	1 (0.3)/398 (99.7)	0 (0.0)/400 (100.0)	0 (0.0)/400 (100.0)
Other ISO (y/n)	0 (0.0)/400 (100.0)	0 (0.0)/400 (100.0)	0 (0.0)/400 (100.0)
Retailers' private protocols			
GLOBALGAP (y/n)	4 (1.1)/395 (98.9)	0 (0.0)/400 (100.0)	0 (0.0)/400 (100.0)
IFS (y/n)	1 (0.3)/398 (99.7)	0 (0.0)/400 (100.0)	1 (0.3)/398 (99.7)
Nature's Choice (y/n)	1 (0.3)/398 (99.7)	0 (0.0)/400 (100.0)	0 (0.0)/400 (100.0)
Others (y/n)	4 (1.1)/395 (98.9)	0 (0.0)/400 (100.0)	0 (0.0)/400 (100.0)

Note: Figures are absolute frequencies (number of answers) and percentages (% of answers) for yes/no questions. n.a. = not available.

farmers (Table 2), mostly refer to the productive function of agriculture, such as improving sale conditions (45.9%), achieving lower labor costs per unit of product (21.7%) and increasing production capacity (11.6%). Second, the factors perceived of as hampering the innovation process are mainly related to financing and costs: lack of funds at the farm (41.2%), high cost (34.1%) and other cost factors (10.1%). Nevertheless, concerns about quality and environment are also important for farmers when producing, such as obtaining healthy products (cited by 61.0%) and respecting the environment (57.3%), as shown in Table 2. Finally, the main research needs identified concern technical questions (genetic improvement for resistance to diseases, 26.6%) and marketing and new markets (olive oil differentiation, 21.6%; non-traditional consuming countries, 16.1%; and international consumer markets, 14.1%).

Farming practices associated with IP

The agricultural practices currently implemented in Andalusia under the IP scheme and a comparison with those used by the rest of farmers are summarized in Table 3. Although Picual is the main olive variety used in planting[58], it is used significantly less by IP farmers than by non-IP ones (62.1 versus 83.7% of farmers, respectively), and conversely Hojiblanca is used more (29.2 versus 4.9%, respectively). Hojiblanca is a milder-flavored variety and has some technical advantages associated with its lesser diffusion in Andalusia, such as less competition for labor at harvest time, fewer fruit set problems and less competition in the market. The Picual variety, on the other hand, presents other important advantages such as higher oil yield, higher rusticity and adaptation to a wider range of conditions, earlier ripening, ease of picking and higher olive stability[59]. In any case, IP farmers seem to be in a more advantageous position than non-IP farmers to sell to extra-local markets in which a milder flavor could be more appreciated and to explore new consumer niches in the local markets.

Soil management practices applied by IP farmers are more environmentally friendly since they consist of extending soil cover and reducing bare soil: 75.6% of IP farmers cover the soil compared to 15.4% of non-IP. This could be related, at least in part, to the steeper slope of the areas where IP farms are located, as we will see later, and the fact that soil covering to avoid erosion is a requirement to apply for certain EU agro-environmental subsidies in sloping areas. Irrigation is less widespread among IP farmers (17.3% of IP versus 31.0% of non-IP), which could be related to the presence of IP in more marginal areas. A higher proportion of IP farmers analyzes water quality before irrigation (81.8 versus 26.2% of non-IP), which is highly recommended. Irrigation has some benefits such as increasing production and generating employment because it requires a little more labor. However, it could have some negative environmental impacts associated with water consumption (a limiting production resource in the region), soil erosion and water contamination. Irrigation practices implemented by IP farmers are therefore superior from an environmental point of view, although it is not clear whether they are better overall. Although irrigation is less common among IP farmers, the application of fertilizers through irrigation water is higher (11.7% of the IP versus 4.1% of the non-IP farmers who irrigate) and application to the leaves with a spray is lower (35.3% versus 52.9%). These fertilization practices could have a negative environmental impact,

Table 2. Attitudes and opinions of Andalusian olive farmers toward innovation.

	Absolute frequencies and percentages
Sources of information on new olive farming practices and CQS	
Other farmers (y/n)	239 (59.8)/160 (40.2)
Personal experience and practice (y/n)	217 (54.3)/183 (45.7)
Agricultural associations (y/n)	210 (52.5)/190 (47.5)
Conferences, fairs, exhibitions, etc. (y/n)	205 (51.4)/194 (48.6)
Suppliers (y/n)	152 (38.2)/247 (61.8)
Papers, radio and television (y/n)	119 (29.7)/281 (70.3)
Internet (y/n)	53 (13.2)/347 (86.8)
Professional and sectorial associations (y/n)	45 (11.2)/355 (88.8)
Public research organizations (y/n)	39 (9.7)/361 (90.3)
Scientific journals and publications (y/n)	20 (5.0)/379 (95.0)
Others (y/n)	10 (2.6)/389 (97.4)
Universities, higher education centers (y/n)	9 (2.3)/390 (97.7)
Customers (y/n)	8 (2.1)/391 (97.9)
Consultants, commercial laboratories, private R&D institutes (y/n)	1 (0.3)/398 (99.7)
Technological centers (y/n)	0 (0.0)/400 (100.0)
Priorities when producing	
Economic profit (None/Little/Some/Quite/A lot)	0 (0.0)/1 (0.3)/5 (1.3)/14 (3.5)/379 (94.9)
Obtaining healthy products (None/Little/Some/Quite/A lot)	0 (0.0)/ 1 (0.4)/19 (4.8)/135 (33.8)/244 (61.0)
Respect for the environment (None/Little/Some/Quite/A lot)	0 (0.0)/ 1 (0.4)/27 (6.7)/142 (35.7)/228 (57.3)
Assuming a low risk (None/Little/Some/Quite/A lot)	0 (0.0)/ 4 (1.1)/31 (7.7)/161 (40.5)/202 (50.7)
Personal prestige (None/Little/Some/Quite/A lot)	1 (0.2)/ 5 (1.3)/34 (8.4)/182 (45.5)/178 (44.6)
Others (None/Little/Some/Quite/A lot)	0 (0.0)/0 (0.0)/0 (0.0)/0 (0.0)/6 (100.0)
Objectives of innovation	
Improving sale conditions	182 (45.9)
Lower labor costs per unit of product	86 (21.7)
Increasing production capacity	46 (11.6)
Greater olives and olive oil quality	19 (4.8)
Respecting the environment	18 (4.5)
Replacing old processes	18 (4.4)
Getting a multifunctional agriculture	15 (3.7)
Improving work conditions	7 (1.7)
Complying with olive regulations	4 (1.0)
Improving IT capabilities	3 (0.6)
Satisfying customers' requirements	0 (0.0)
Increasing prestige	0 (0.0)
Others	0 (0.0)
Factors that difficult innovation	
Lack of on-farm funds	165 (41.2)
Too high cost	136 (34.1)
Other cost factors	40 (10.1)
Lack of off-farm funds (outer financing)	35 (8.8)
Dominance of established enterprises	11 (2.7)
Lack of information about technology	9 (2.3)
Lack of qualified staff	1 (0.3)
Lack of information about markets	1 (0.3)
Difficulties in finding R&D partners	0 (0.0)
Other knowledge factors	0 (0.0)
Uncertainty about the demand of innovative goods and services	0 (0.0)
No demand of innovations	0 (0.0)
Other market factors	0 (0.0)
Demanded research topics	
Olive genetic improvement: resistance to Verticillium disease	106 (26.6)
Marketing implications of the olive oil differentiation	86 (21.6)
Olive oil in non-traditional consuming countries	64 (16.1)
Consumer behaviour in international markets	56 (14.1)

Table 2 (continued)

	Absolute frequencies and percentages
Using covers for disinfection of soils affected by Verticillium disease	46 (11.6)
Irrigation, estimation of irrigation thresholds. Control of alternate bearing	19 (4.8)
Potential demand of new products with olive oil and demand of by-products	15 (3.8)
Innovation in production, sustainability and use of olive waste	3 (0.9)
Other research topics related to marketing, organization, assets and territory	3 (0.6)

Note: Figures are absolute frequencies (number of answers) and relative frequencies (% of answers) for (1) yes/no questions; (2) more than two options and single choice questions.

greater in the case of IP farmers. Conversely, the application of phytosanitary treatments is more rational from an agronomic and environmental perspective in the case of IP, since this is done to a greater extent only when the infestation/infection surpasses a determined threshold or in response to expert advice (50.8% of IP versus 21.8% of non-IP farmers). It is worth noting that both types of farmers do implement some recommended practices with no significant differences between them, such as localizing the phytosanitary treatments on the source of infestation (done by less than 4% of both types of farmers).

With regard to harvesting, collecting the fallen olives from the ground through mechanical means is more common among IP farmers (61.2%) than among non-IP ones (35.0%). The use of specific machinery can replace a huge amount of labor and reduce costs for farmers in the long term. In marginal areas, where IP is more common, this could be vital to the survival of olive farms. The separation of the olives picked from ground and trees is also more common for IP farmers (95.3% of IP versus 60.8% of non-IP), which is recommended for obtaining a high-quality olive oil. Management of small pruning offcuts is more rational from an environmental point of view for IP farmers since they shred and incorporate them into the ground more (56.7% of IP versus 21.9% of non-IP) and burn less (41.8 versus 77.5% of non-IP). The remaining practices referring to transport, pruning and management of other by-products are not statistically different for IP and non-IP farmers, with one noteworthy common factor being the scarce use of boxes when transporting the olives, which is recommended to avoid their deterioration and a subsequent decrease in quality.

Adoption factors of IP

Differences between the farmers and farms using IP and the rest can be related to and serve to explain the adoption of IP (Fig. 2). With regard to the characteristics, attitudes and opinions of farmers (Table 4), both types are mainly owner and active farmers (91.0% of IP and 92.4% of non-IP) although there are more IP producers who are tenants (9.0 versus 2.2% of non-IP). IP farmers play more of a dual role on the farm, doing management and physical work simultaneously (91.3 versus 77.2% of non-IP), whereas performing, exclusively, management duties or physical activities is more frequent in the case of non-IP. This indicates that IP farmers are more wholeheartedly dedicated to agriculture. Moreover, IP farmers belong more frequently than the rest to agricultural cooperatives (96.8% of IP versus 77.8% of non-IP), PDO schemes (34.8 versus 12.3%) and, logically, associations of IP farmers (69.0 versus 1.7%) although less to agricultural unions (3.7 versus 14.3%). This indicates that IP farmers are, in general, more connected to professional networks, which are some of the most important sources of information for Andalusian olive farmers, as discussed previously. It must also be highlighted that both types of farmers, with no significant differences, are mainly middle-aged and older (46–65 years), male, with primary level education, experienced in agriculture (11–30 years) and wholly or mainly reliant on agriculture for their income. In line with their greater involvement in professional networks, the sources of information of IP producers are based to a greater extent on agricultural associations (93.3 versus 44.3% of non-IP) and other farmers (80.6 versus 55.7%), that is, to say, sources that are internal to the production system, and less on their personal experience and practice (32.7 versus 58.6%) and external sources such as suppliers (6.0 versus 44.7%), papers, radio and television (13.1 versus 33.0%), and public research organizations (0.0 versus 11.6%). This highlights the importance of personal contact with other farmers and agricultural associations as a source of information for IP farmers, and the relatively low importance of sources outside the production system. Although their priorities as producers and the objectives of innovation for both types of farmers are not different, these mainly being linked to economic and productive aspects as shown previously, they differ on the factors that hamper the innovation and the topics that need to be researched. Thus, high cost is the main factor that hinders the innovation for IP farmers (49.4% compared to 31.1% of non-IP), whereas lack of funds at the farm is the most important factor cited by non-IP farmers (44.1% compared to 26.9% of IP). This could be related to the extra costs that IP implantation and implementation can entail and this is highlighted by those who have already adopted IP and the potentially lower financial solvency of non-IP farmers. With respect to their research demands, IP farms are more interested

Table 3. Farming practices implemented by IP and non-IP farmers.

	Absolute frequencies and percentages		Correlation statistics[1]	
	IP	Non-IP	χ^2 (d.f.)	*P* (sign.)
Planting				
Olive variety			33.282 (5)	0.000 (**)
Picual	42 (62.1)	278 (83.7)		
Hojiblanca	20 (29.2)	16 (4.9)		
Picudo	3 (3.9)	20 (6.0)		
Others	3 (4.9)	11 (3.2)		
Arbequina	0 (0.0)	5 (1.6)		
Lechin of Sevilla	0 (0.0)	2 (0.6)		
Lechin of Granada	0 (0.0)	0 (0.0)		
Soil management				
Main soil management technique			109.075 (3)	0.000 (**)
Bare soil, little tillage, or shallow tillage, weed control with herbicides	12 (17.3)	134 (40.5)		
Soil covered by spontaneous or cultivate plants	51 (75.6)	51 (15.4)		
Bare soil, no tillage, weed control with herbicides	3 (5.1)	81 (24.6)		
Bare soil, conventional farming (constant tillage)	1 (1.9)	64 (19.5)		
Irrigation				
Irrigation (y/n)	12 (17.3)/55 (82.7)	103 (31.0)/229 (69.0)	4.056 (1)	0.044 (*)
Irrigation system			0.595 (2)	0.743 (n.s.)
Trickle irrigation	12 (100.0)	99 (97.3)		
Flooding irrigation	0 (0.0)	2 (2.1)		
Sprinkler irrigation	0 (0.0)	1 (0.6)		
Timing of irrigation			1.120 (1)	0.290 (n.s.)
Fixed calendar (non-depending on crop needs)	5 (41.7)	64 (62.1)		
Following expert advice (depending on crop needs)	7 (58.3)	39 (37.9)		
Analysis of water quality	9 (81.8)/2 (18.2)	27 (26.2)/76 (73.8)	4.872 (1)	0.027 (*)
Fertilization				
Fertilization (y/n)	67 (100.0)/0 (0.0)	332 (99.9)/0 (0.1)	0.000 (1)	1.000 (n.s.)
Method for the application of fertilizers			10.578 (2)	0.005 (**)
Spray application to the leaves	24 (35.3)	175 (52.9)		
Direct application to the soil	36 (53.0)	142 (43.0)		
Through irrigation water (fertirrigation)	8 (11.7)	14 (4.1)		
Fertilizers used			0.472 (1)	0.492 (n.s.)
Inorganic fertilizers (NPK)	67 (100.0)	326 (98.2)		
Organic fertilizers (pruning offcuts, compost, etc.)	0 (0.0)	6 (1.8)		
Analysis before fertilization			0.982 (1)	0.322 (n.s.)
None	39 (58.2)	218 (65.5)		
Soil or leaf	28 (41.8)	115 (34.5)		
Phytosanitary treatments				
Phytosanitary treatments (y/n)	67 (100.0)/0 (0.0)	330 (99.1)/3 (0.9)	0.000 (1)	0.997 (n.s.)
Treatment of olive fruit fly (*Bactrocera oleae*)			2.963 (2)	0.227 (n.s.)
Non-biological insecticide	61 (95.1)	182 (98.4)		
Mass traps (one trap per tree = pheromones + glue + pyrethroids)	2 (2.9)	1 (0.3)		
Biological control (*Opius concolor*)	1 (2.0)	2 (1.3)		
Treatment of olive moth (*Prays oleae*)			0.005 (1)	0.944 (n.s.)
Chemical treatments	64 (100.0)	284 (99.0)		
Biological control (*Bacillus thuringiensis*)	0 (0.0)	3 (0.9)		
Treatment of peacock spots, olive leaf blotch, olive leaf spot (*Spilocaea oleagina*/*Cycloconium oleaginum*)			0.953 (1)	0.329 (n.s.)
Copper fungicides	64 (100.0)	320 (97.1)		
Pruning to clear	0 (0.0)	10 (2.9)		
Other chemical treatments	0 (0.0)	0 (0.0)		

Table 3 (continued)

	Absolute frequencies and percentages		Correlation statistics[1]	
	IP	Non-IP	χ^2 (d.f.)	*P* (sign.)
Timing of the phytosanitary treatments			22.026 (1)	0.000 (*)
On a fixed calendar basis or with the first symptoms of infestation/infection	32 (49.2)	253 (78.2)		
When the infestation/infection surpasses a determined threshold or in response to expert advice	33 (50.8)	70 (21.8)		
Localization of the phytosanitary treatments			2.639 (1)	0.104 (n.s.)
The whole plantation	63 (96.1)	320 (99.0)		
Only the source of infestation/infection	3 (3.9)	3 (1.0)		
Harvesting				
Timing of the harvest			3.654 (1)	0.056 (n.s.)
According to a fruit ripeness index	44 (66.0)	256 (77.5)		
On a fixed calendar basis	23 (34.1)	74 (22.5)		
Method for collecting the fallen olives from ground			17.517 (2)	0.000 (**)
By hand	26 (38.8)	200 (60.2)		
Mechanical means	41 (61.2)	116 (35.0)		
No collecting	0 (0.0)	16 (4.9)		
Method for picking the olives from the trees			0.397 (1)	0.529 (n.s.)
Branch or trunk vibrators	64 (96.1)	307 (92.5)		
Hand-pole beating	3 (3.9)	25 (7.6)		
Handpicking	0 (0.0)	0 (0.0)		
Separation of ground and tree olives (y/n)	64 (95.5)/3 (4.5)	202 (60.8)/130 (39.2)	28.630 (1)	0.000 (**)
Transport				
Ways of carrying the olives from the olive grove to the mill			3.756 (2)	0.153 (n.s.)
In the tractor or lorry trailer	67 (100.0)	322 (97.0)		
Sacks	0 (0.0)	8 (2.5)		
Boxes	0 (0.0)	2 (0.5)		
Pruning				
Main pruning technique			3.620 (1)	0.057 (n.s.)
Traditional, severe, each 1 or 2 years	58 (87.0)	248 (75.0)		
Low-intensity pruning, every 2 or 3 years	9 (13.1)	83 (25.0)		
Management of by-products				
Wood			0.265 (1)	0.606 (n.s.)
Combustible	66 (98.1)	320 (96.2)		
Others	1 (1.9)	12 (3.8)		
Furniture manufacture	0 (0.0)	0 (0.0)		
Small-sized pruning offcuts			33.298 (3)	0.000 (**)
Burning	28 (41.8)	258 (77.5)		
Shredding and incorporation into the ground	38 (56.7)	73 (21.9)		
Combustible	1 (1.5)	2 (0.6)		
Animal food	0 (0.0)	0 (0.0)		
Leaves			0.481 (2)	0.786 (n.s.)
Others	3 (66.7)	13 (62.7)		
Combustible	1 (33.3)	6 (30.7)		
Animal food	0 (0.0)	1 (6.6)		
Therapeutic uses: hypertension, astringents, etc.	0 (0.0)	0 (0.0)		

[1] Corrected Yates χ^2 for contingent tables when degree of freedom (d.f.) = 1; (2) Pearson χ^2 for contingent tables when d.f. > 1; (3) χ^2 for bivariate logit when proof for contingent tables is not statistically reliable. Significance (sign.): $^{**}P \leq 0.01$; $^{*}\ 0.01 < P \leq 0.05$; n.s. = not significant; y/n = yes/no.

in market-related topics, such as consumer behavior in international markets and the marketing implications of olive oil differentiation, and less on technical issues, such as genetic improvement, irrigation, etc. This highlights the greater focus of IP farmers on new and international markets.

Table 4. Characteristics, attitudes and opinions of IP and non-IP farmers.

	Absolute frequencies and percentages		Correlation statistics[1]	
	IP	Non-IP	χ^2 (d.f)	*P* (sign.)
Characteristics of farmers				
Age (year)			7.047 (5)	0.217 (n.s.)
18–25	0 (0.0)	4 (1.1)		
26–35	7 (10.7)	19 (5.6)		
36–45	11 (16.3)	43 (12.8)		
46–55	24 (36.3)	98 (29.4)		
56–65	18 (26.5)	123 (36.9)		
>65	7 (10.2)	47 (14.1)		
Sex			0.898 (1)	0.343 (n.s.)
Male	61 (91.3)	316 (94.9)		
Female	6 (8.7)	17 (5.1)		
Civil state			6.647 (4)	0.156 (n.s.)
Married	60 (88.8)	289 (86.8)		
Single	7 (11.2)	27 (8.2)		
Widower/widow	0 (0.0)	9 (2.7)		
Separated	0 (0.0)	6 (1.9)		
Others	0 (0.0)	1 (0.4)		
Education level			8.398 (5)	0.136 (n.s.)
Primary education	41 (61.0)	161 (48.5)		
No education	9 (13.1)	84 (25.3)		
Secondary education	4 (6.0)	36 (11.0)		
Medium graduate	5 (6.8)	22 (6.6)		
High graduate	6 (8.2)	18 (5.4)		
Vocational training	3 (4.9)	11 (3.2)		
Legal status with respect to the farm			12.357 (3)	0.006 (**)
Owner and active farmer	61 (91.0)	305 (92.4)		
Tenant farmer	6 (9.0)	7 (2.2)		
Wage earner	0 (0.0)	13 (3.8)		
Other	0 (0.0)	5 (1.6)		
Dedication to agriculture (years)			7.708 (3)	0.052 (n.s.)
0–10	10 (15.0)	37 (11.2)		
11–20	12 (17.3)	82 (25.0)		
21–30	27 (40.5)	85 (25.9)		
>30	18 (27.1)	124 (37.9)		
Importance of agriculture in final income			3.126 (3)	0.373 (n.s.)
Total	20 (30.3)	129 (38.8)		
Partial main	30 (44.9)	114 (34.2)		
Partial secondary	13 (19.9)	74 (22.3)		
Marginal	3 (4.9)	15 (4.7)		
Agricultural training			6.845 (4)	0.144 (n.s.)
Experience	29 (43.2)	171 (51.8)		
Courses, lectures, etc.	31 (46.8)	144 (43.6)		
Agricultural university education	3 (3.9)	11 (3.2)		
Agricultural vocational training	4 (6.1)	4 (1.1)		
Others	0 (0.0)	1 (0.4)		
Type of work in the farm			7.110 (2)	0.029 (*)
Management and physical work	61 (91.3)	255 (77.2)		
Exclusively management	6 (8.7)	62 (18.6)		
Exclusively physical work	0 (0.0)	14 (4.1)		
Membership of associations or agricultural collectives				
Agricultural cooperatives (y/n)	65 (96.8)/2 (3.2)	259 (77.8)/74 (22.2)	12.19 (1)	0.000 (**)
PDO (y/n)	23 (34.8)/44 (65.2)	41 (12.3)/291 (87.7)	18.399 (1)	0.000 (**)
Association of integrated farmers (y/n)	46 (69.0)/21 (31.0)	6 (1.7)/327 (98.3)	214.555 (1)	0.000 (**)

Table 4 (continued)

	Absolute frequencies and percentages		Correlation statistics[1]	
	IP	Non-IP	χ^2 (d.f)	*P* (sign.)
Agricultural union (y/n)	2 (3.7)/65 (96.3)	47 (14.3)/285 (85.7)	5.463 (1)	0.019 (*)
Associations for Integrated Pest Management (y/n)	5 (7.7)/62 (92.3)	10 (3.1)/322 (96.9)	1.946 (1)	0.163 (n.s.)
Agricultural Transformation Society (y/n)	0 (0.0)/ 67 (100)	2 (0.6)/330 (99.4)	0.000 (1)	1.000 (n.s.)
Association of organic farmers (y/n)	0 (0.0)/67 (100.0)	2 (0.5)/331 (99.5)	0.000 (1)	1.000 (n.s.)
Others (y/n)	0 (0.0)/67 (100.0)	0 (0.1)/332 (99.9)	0.791 (1)	0.374 (n.s.)
Prospects of continuity in the agricultural activity			1.044 (1)	0.307 (n.s.)
Continuing until retirement	54 (82.9)	252 (76.4)		
Leaving before retirement	11 (17.1)	78 (23.6)		
If CAP subsidies disappear, how would it affect your continuity in agriculture			2.010 (1)	0.156 (n.s.)
Would probably leave	38 (56.1)	222 (66.6)		
Would continue	29 (43.9)	111 (33.4)		
Future of the olive farm			6.925 (3)	0.074 (n.s.)
Children will inherit it	56 (87.5)	245 (75.9)		
Will rent it	5 (8.5)	30 (9.3)		
Will sell it	1 (2.0)	34 (10.4)		
Other	1 (2.0)	14 (4.3)		
Attitudes and opinions of farmers				
Sources of information on new olive farming practices and CQSs				
Other farmers (y/n)	54 (80.6)/13 (19.4)	185 (55.7)/147 (44.3)	13.343 (1)	0.000 (**)
Personal experience and practice (y/n)	22 (32.7)/45 (67.3)	195 (58.6)/138 (41.4)	3.851 (1)	0.000 (**)
Agricultural associations (y/n)	63 (93.3)/4 (6.7)	147 (44.3)/185 (55.7)	53.375 (1)	0.000 (**)
Conferences, fairs, exhibitions, etc. (y/n)	36 (54.3)/31 (45.7)	169 (50.8)/164 (49.2)	0.097 (1)	0.755 (n.s.)
Suppliers (y/n)	4 (6.0)/63 (94.0)	148 (44.7)/184 (55.3)	33.619 (1)	0.000 (**)
Papers, radio and television (y/n)	9 (13.1)/58 (86.9)	110 (33.0)/223 (67.0)	9.337 (1)	0.002 (**)
Internet (y/n)	12 (17.5)/55 (82.5)	41 (12.3)/292 (87.7)	1.073 (1)	3.00 (n.s.)
Professional and sectorial associations (y/n)	6 (9.5)/61 (90.5)	39 (11.6)/294 (88.4)	0.193 (1)	0.66 (n.s.)
Public research organizations (y/n)	0 (0.0)/67 (100.0)	39 (11.6)/294 (88.4)	7.415 (1)	0.006 (**)
Scientific journals and publications (y/n)	6 (8.7)/61 (91.3)	14 (4.3)/318 (95.7)	1.728 (1)	0.189 (n.s.)
Others (y/n)	9 (13.1)/58 (86.9)	1 (0.4)/331 (99.6)	34.153 (1)	0.000 (**)
Universities, higher education centers (y/n)	0 (0.0)/67 (100.0)	9 (2.8)/323 (97.2)	0.832 (1)	0.362 (n.s.)
Customers (y/n)	0 (0.0)/67 (100.0)	8 (2.5)/324 (97.5)	0.649 (1)	0.420 (n.s.)
Consultants, commercial laboratories, private R&D institutes (y/n)	0 (0.0)/67 (100.0)	1 (0.4)/331 (99.6)	0.000 (1)	1.000 (n.s.)
Technological centers (y/n)	0 (0.0)/67 (100.0)	0 (0.0)/333 (100.0)	–	–
Priorities when producing				
Economic profit (None–Little/Some–Quite–A lot)	0 (0.0)/0 (0.0)/0 (0.0)/3 (4.4)/64 (95.6)	0 (0.0)/1 (0.4)/5 (1.5)/11 (3.4)/315 (94.7)	2.519 (3)	4.472 (n.s.)
Obtaining healthy products (None–Little/Some–Quite–A lot)	0 (0.0)/0 (0.0)/1 (1.2)/ 21 (31.5)/45 (67.3)	0 (0.1)/1 (0.4)/18 (5.5)/ 114 (34.3)/198 (59.7)	4.101 (4)	0.393 (n.s.)
Respect for the environment (None–Little/Some–Quite–A lot)	0 (0.0)/0 (0.0)/4 (5.9)/ 24 (36.0)/38 (58.1)	0 (0.0)/1 (0.4)/23 (6.8)/ 118 (35.6)/190 (57.1)	0.592 (3)	0.898 (n.s.)
Assuming a low risk (None–Little/ Some–Quite–A lot)	0 (0.0)/1 (1.3)/6 (9.4) /33 (49.5)/26 (39.8)	0 (0.1)/4 (1.1)/24 (7.4)/ 129 (38.7)/176 (52.8)	3.857 (4)	0.426 (n.s.)
Personal prestige (None–Little/Some–Quite–A lot)	0 (0.0)/2 (2.4)/4 (5.8)/ 32 (47.5)/30 (44.3)	1 (0.2)/4 (1.1)/30 (8.9)/ 150 (45.0)/149 (44.7)	1.707 (4)	0.789 (n.s.)
Others (None–Little/Some–Quite–A lot)	0 (0.0)/0 (0.0)/0 (0.0)/0 (0.0)/2 (100.0)	0 (0.0)/0 (0.0)/0 (0.0) /0 (0.0)/4 (100.0)	–	–
Objectives of innovation			11.741 (9)	0.228 (n.s.)
Improving sale conditions	37 (55.7)	144 (43.9)		
Lower labor costs per unit of product	13 (18.9)	73 (22.3)		
Increasing production capacity	6 (8.2)	40 (12.3)		

Table 4 (continued)

	Absolute frequencies and percentages		Correlation statistics[1]	
	IP	Non-IP	χ^2 (d.f)	*P* (sign.)
Greater olives and olive oil quality	4 (5.2)	15 (4.7)		
Respecting the environment	5 (6.8)	13 (4.1)		
Replacing old processes	2 (3.2)	15 (4.7)		
Getting a multifunctional agriculture	0 (0.0)	15 (4.4)		
Improving work conditions	1 (1.9)	5 (1.7)		
Complying with olive regulations	0 (0.0)	4 (1.2)		
Improving IT capabilities	0 (0.0)	3 (0.8)		
Satisfying customers' requirements	0 (0.0)	0 (0.0)		
Increasing prestige	0 (0.0)	0 (0.0)		
Others	0 (0.0)	0 (0.0)		
Factors hindering innovation			16.013 (8)	0.042 (*)
Lack of on-farm funds	18 (26.9)	147 (44.1)		
Too high cost	33 (49.4)	103 (31.1)		
Other cost factors	6 (8.7)	35 (10.4)		
Lack of off-farm funds (outer financing)	4 (6.7)	31 (9.2)		
Dominance of established enterprises	3 (4.4)	8 (2.4)		
Lack of information about technology	1 (1.9)	8 (2.4)		
Lack of qualified staff	1 (1.9)	0 (0.0)		
Lack of information about markets	0 (0.0)	1 (0.4)		
Difficulties in finding R&D partners	0 (0.0)	0 (0.0)		
Other knowledge factors	0 (0.0)	0 (0.0)		
Uncertainty about the demand of innovative goods and services	0 (0.0)	0 (0.1)		
No demand of innovations	0 (0.0)	0 (0.0)		
Other market factors	0 (0.0)	0 (0.0)		
Demanded research topics			50.956 (8)	0.000 (**)
Olive genetic improvement: resistance to Verticillium disease	5 (7.7)	101 (30.4)		
Marketing implications of the olive oil differentiation	24 (36.0)	62 (18.8)		
Olive oil in non-traditional consuming countries	12 (18.4)	52 (15.6)		
Consumer behavior in international markets	20 (30.0)	36 (10.8)		
Using covers for disinfection of soils affected by Verticillium disease	1 (1.9)	45 (13.5)		
Irrigation, estimation of irrigation thresholds. Control of alternate bearing	1 (1.9)	18 (5.4)		
Potential demand of new products with olive oil and demand of by-products	1 (0.9)	14 (4.3)		
Other research topics related to innovation in production, sustainability and use of olive waste	2 (3.2)	1 (0.4)		
Other research topics related to marketing, organization, assets and territory	0 (0.0)	3 (0.8)		

[1] Corrected Yates χ^2 for contingent tables when degree of freedom (d.f.) = 1; (2) Pearson χ^2 for contingent tables when d.f. > 1; (3) χ^2 for bivariate logit when proof for contingent tables is not statistically reliable. Significance (sign.): $^{**}P \leq 0.01$; $^{*}0.01 < P \leq 0.05$; n.s. = not significant; y/n = yes/no.

With respect to the structural characteristics of farms (Table 5), the most important differences are that IP farms are located to a greater extent than non-IP ones in less favored areas on steeper slopes (mainly medium for IP versus low for non-IP), thus they are less productive on average (mainly 2000–6000 kg olives ha^{-1} versus 4000–8000 for non-IP), and are more often managed in a traditional non-intensive way (97.6 versus 82.4% of non-IP). In addition, IP farms use 'family labor supplemented with wage earners' more (60.4 versus 42.5% of non-IP) and 'exclusively wage-earner labour' less. In terms of destination, the olives produced by IP farmers are

Table 5. Structural characteristics of IP and non-IP farms.

	Absolute frequencies and percentages		Correlation statistics[1]	
	IP	Non-IP	χ^2 (d.f)	*P* (sign.)
Characteristics of farms				
Olive surface area (ha)			2.645 (3)	0.450 (n.s)
[0–1]	0 (0.0)	6 (1.8)		
[1–5]	27 (40.9)	137 (41.3)		
[5–10]	16 (24.2)	97 (29.2)		
[10-]	23 (34.8)	92 (27.7)		
Organic olive grove (y/n)	0 (0.0)/67 (100.0)	6 (1.8)/326 (98.2)	0.312 (1)	0.576 (n.s.)
Type of cultivation			13.725 (2)	0.001 (**)
Traditional	65 (97.6)	261 (82.4)		
Intensive	2 (2.4)	54 (17.2)		
Super-intensive	0 (0.0)	1 (0.4)		
Yield (kg olives ha^{-1})			25.173 (4)	0.000 (**)
< 2000	4 (6.3)	18 (5.5)		
2000–4000	11 (15.8)	65 (19.7)		
4000–6000	50 (75.1)	151 (45.7)		
6000–8000	2 (2.8)	85 (25.5)		
> 8000	0 (0.0)	12 (3.6)		
Age of the olive plantation (years)			7.372 (3)	0.061 (n.s.)
< 10	2 (2.4)	29 (8.8)		
10–50	38 (56.6)	169 (50.7)		
51–100	25 (37.8)	99 (29.7)		
> 100	2 (3.2)	36 (10.7)		
Labor			22.397 (5)	0.000 (**)
Family and temporary wage-earner	40 (60.4)	141 (42.5)		
Exclusively family	23 (33.9)	103 (30.9)		
Exclusively temporary wage-earner	4 (5.6)	49 (14.9)		
Temporary and permanent wage-earner	0 (0.0)	35 (10.6)		
Family, temporary and permanent wage-earner	0 (0.0)	2 (0.6)		
Exclusively permanent wage-earner	0 (0.0)	1 (0.4)		
Family and permanent wage-earner	0 (0.0)	0 (0.0)		
Destination of the product			1.313 (2)	0.519 (n.s.)
Olive oil	67 (100.0)	329 (98.9)		
Table olives	0 (0.0)	1 (0.2)		
Both	0 (0.0)	3 (0.9)		
Soil slope			20.292 (2)	0.000 (**)
Low	11 (16.1)	147 (44.4)		
Medium	33 (48.6)	121 (36.6)		
High	24 (35.4)	63 (19.0)		
Inserted cultivations (y/n)	0 (0.0)/67 (100.0)	4 (1.2)/329 (98.8)	0.052 (1)	0.819 (n.s.)
Livestock management (y/n)	0 (0.0)/67 (100.0)	1 (0.2)/332 (99.8)	0.000 (1)	1.000 (n.s.)
Main customer			16.589 (1)	0.000 (**)
First degree cooperative mills	64 (94.9)	240 (72.3)		
Independent oil mills	3 (5.1)	92 (27.7)		
Second degree cooperative mills	0 (0.0)	0 (0.0)		
Canning and bottling enterprises	0 (0.0)	0 (0.0)		
Refineries	0 (0.0)	0 (0.0)		
Refineries-bottling enterprises	0 (0.0)	0 (0.0)		
Oil extraction enterprises	0 (0.0)	0 (0.0)		
Wholesaling in destination	0 (0.0)	0 (0.0)		
Distribution platforms (hypermarkets, etc.)	0 (0.0)	0 (0.0)		
Buy centrals	0 (0.0)	0 (0.0)		
Retailers	0 (0.0)	0 (0.0)		
Final consumers	0 (0.0)	0 (0.0)		
Others	0 (0.0)	0 (0.0)		
Main localization of customers				
Andalusia	66 (100.0)	330 (100.0)		

[1] Corrected Yates χ^2 for contingent tables when degree of freedom (d.f.) = 1; (2) Pearson χ^2 for contingent tables when d.f. > 1; (3) χ^2 for bivariate logit when proof for contingent tables is not statistically reliable. Significance (sign.): $^{**}P \leq 0.01$; $^{*}\ 0.01 < P \leq 0.05$; n.s. = not significant; y/n = yes/no.

more frequently destined to cooperative mills (94.9 versus 72.3% of non-IP) and less to independent olive mills (5.1 versus 27.7% of non-IP), which is in accordance with their higher membership to agricultural cooperatives as shown above.

Discussion

Quality differentiation and certification are key issues for the future of the olive agrofood sector. The competitiveness of the olive-growing sector depends heavily on the adaptation capacity of its economic agents to the changing conditions of the markets and the institutional environment. Issues such as food quality, protection of the environment, good farming practices, survival of the rural world and sustainability of agriculture have been incorporated over recent decades into the demands of an increasing number of consumers and citizens in general[23]. This phenomenon, especially notable in developed countries, the main destination of olive oil, is the result of changes in demographic and socio-cultural variables, consumer attitudes and the development of new lifestyles[60]. In the supply part of the agrofood chain, diverse CQSs have been emerging since the 20th century as institutional innovations[61] induced, among other factors, by technical changes such as the availability of new production techniques, and alterations in the demand of consumers. A farmer adopting a CQS is the outcome of a complex push and pull process of simultaneously acting forces, consisting of not only final consumers but also intermediate customers and the farmer's own management practices[62]. IP stands out in the Andalusian olive-growing sector as a CQS backed by public regulations, which certifies the quality of the product as a result of the implementation of a set of farming practices intended to be more sustainable, environmentally friendly, profitable, fair for farmers and healthy for consumers. IP allows qualities that are 'extrinsic to the product', such as biodiversity conservation, to be introduced into the commodity through monitoring at the point of production[63]. IP farming practices may represent a technological innovation for many farmers in the sense that they are techniques that are not commonly known and used.

The results corroborated the higher quality of IP olive products and processes since IP is associated with a wider use of better farming practices from an agronomic, environmental and/or economic perspective, despite IP farms being located in less favored regions. This is in agreement with other previous studies[18,23,47] which highlight the higher performance of IP both overall and for each of the three dimensions of sustainability: economic, social and environmental (especially the latter of these). However, we cannot conclude that the higher quality of IP olive growing is due to the IP requirements *per se,* but rather to the manner in which the IP practices are really implemented within the restrictions which the IP norm imposes. Indeed, as previously stated, the IP olive norm is not completely fixed and allows some degree of flexibility, since some practices are only recommended. The majority of IP olive farmers interviewed implement agricultural practices in accordance with IP regulations, as is logical. If some mandatory/forbidden farming practice is not respected by a farmer and this is detected by control measures, the field technician performing the check can take provisional measures, up to and including the withdrawal of IP certification. Our results, however, must be interpreted carefully, since the study was carried out for the main Andalusian olive zone and average conditions. In other scenarios of productivity, climate, etc., the results may change and need to be further investigated in order to fine-tune policy design[18]. Moreover, our methodological approach entails some simplifications and assumptions, as for any model. It does not allow us to determine, for example, the direct effect of adoption factors on the practices implemented, but rather only the indirect effect of adoption factors, through the adoption of IP, on these practices, nor have potential inner relationships among adoption factors, or among practices, been taken into account. All these issues remain as further refinements for future research.

This research also confirms the scarce knowledge of adoption of, and intention to adopt, most of the CQSs by the Andalusian olive farmers. The reason may be the fact that, logically, although they acknowledge the importance of obtaining healthy products and respecting the environment, their main priority is their economic profit as producers, and they perceive the adoption of technological innovations in general as costly processes they cannot afford due to lack of funds. With regard to their information channels, olive farmers seem to be entrenched in a relatively closed information system where 'contagion' of information among themselves and close sources is the main diffusion driver. The importance of interpersonal contact and contagion in the diffusion of IP, which was also pointed out in some previous studies on organic olive growing in Andalusia[46], highlights the 'information-intensive' nature of the process and the practical complexity of this innovation. In the current market conditions, in which consumers are demanding new food products that are safer and more sophisticated, while private businesses and the public sector try to recover credibility and consumer confidence, those most affected are the small-scale producers and processors, since they have had to confront additional costs related to quality assurance[60]. Special emphasis should therefore be placed on the benefits of adopting CQS in the medium to long term, such as improved competitiveness and higher product quality[64]. Farmers need to be aware that the quality is in increasing demand in the markets and that the economic benefits of adopting a CQS can exceed the costs of its implementation[35,65,66]. Improved access to

credit would probably also increase the adoption of CQS, although this depends on macroeconomic conditions, and expectations regarding the current context of global crisis are not clear. Credit could be channeled through agricultural associations to which Andalusian olive farmers are especially related. Apart from this, a change in mentality is required of farmers, who need to be convinced of the multiple functions of agriculture and the environmental and social benefits of IP insofar as it can condition the legitimacy of public support for agriculture in the near future. The efforts of external R&D institutions, both public and private, to tackle this knowledge transfer to the sector should be encouraged and a greater connection of these institutions with the internal networks of information for farmers is advisable, since the economic success of farmers adopting CQS may depend on them attending training programs[67]. Public institutions in particular should increase their involvement and support in the diffusion of IP due to the greater sustainability of this farming system and the improved welfare of society as a whole. Given the importance of interpersonal contact among farmers for the diffusion of this complex innovation, demonstrations of the experience of those who have already adopted IP could be an effective way of communicating and stimulating other farmers. Furthermore, alternative communication channels should be explored and encouraged, such as the use of IT for educating and training farmers, which is currently hardly used. However, given the socio-demographic characteristics of Andalusian olive farmers (mainly 46–65 years old and with primary level education), the widespread use of alternative channels may be a strategy confined to the medium to long term. This highlights, moreover, the importance of policies for the rejuvenation and formal education of the sector. Some of the factors that can explain the relative success of the diffusion of IP in the Andalusian olive-growing sector are the more complete and professional dedication of IP farmers to agriculture, their stronger links with professional networks, their greater presence in marginal areas where the olive is managed in a family-based, traditional and non-intensive manner and where the adoption of a CQS can represent an important strategy to compete in the market through the certification of quality, and their greater orientation toward new markets.

The demand part also needs important improvement. In effect, despite IP market and demand being one of the research topics most demanded by farmers, the lack of specific studies on this aspect is patent. More information is needed about the acceptance and demand for IP in national and international markets and consumers' willingness to pay. Although the available data indicate that IP has a moderate share of Andalusian agricultural production, it is not known which part of this production is finally marketed as IP and at what prices. This information, which is available for other CQSs such as organic agriculture and PDO, can be decisive for farmers when considering whether to adopt a quality system. Lack of market acceptance can be a major obstacle for the development of agrofood certification[68]. Research on other CQSs indicates that it is necessary to stimulate 'quality culture' among consumers. Indeed, levels of knowledge and perception of quality are very low in the olive markets[33,39]. The act of educating and informing consumers is therefore one of the most important strategies to further boost the consumption and development of CQSs. In the specific case of IP, emphasis should be placed on its overall quality, that is to say, on the environmental and social benefits above and beyond the higher intrinsic quality of the product, which lead to greater sustainability in the production process and the greater welfare of society as a whole.

Conclusions

This paper aims to fill a patent gap in the literature regarding: (1) the underlying factors conditioning the adoption of IP in the Andalusian olive-growing sector, i.e., the most relevant CQS in the most important olive-producing region worldwide; and (2) the comparison of the farming practices really implemented by adopters and non-adopters of IP and their adequacy from an agronomic, environmental and economic perspective. The results confirm the hypothetically higher quality of IP olive agriculture due to the implementation of better farming practices, which are, in general, more sustainable, environment friendly, profitable, fair for farmers and healthy for consumers. The IP practices regarded as especially good are those related to soil management, irrigation, phytosanitation and harvesting. However, certain good practices are scarcely used by IP farmers and there is room for improvement, including the application of fertilizers to the leaves with spray, localizing the phytosanitary treatments on the source of infestation and the use of sacks for transporting the olives.

The results highlight the high impact on farmers' behavior of sources of information internal to the agricultural system, such as other farmers, self-study, agricultural associations, etc., and the low importance of external sources, such as technological centers, consultants, commercial laboratories, private R&D institutes, customers, universities and public research organizations. Moreover, a lack of orientation of the farmers toward the rest of the agrofood system is patent, since they do not pursue the objective of satisfying customers' requirements when innovating. Further extending the diffusion of innovations in general and CQS in particular would require bringing information closer to farmers in an accessible manner. The work of R&D institutions should focus more closely on this aspect. Information should meet the R&D needs of the sector, especially those linked to technical and marketing questions, and contribute to clarifying their financial concerns by emphasizing the medium- to long-term improved competitiveness of IP.

The environmental and social benefits of IP need to be appreciated by farmers as an added value increasingly demanded by consumers and society in general. The importance of promoting the professionalization and rejuvenation of the sector is also patent. Finally, we should also highlight the need for further research and development in the market and in the demand for IP.

Acknowledgements. The authors acknowledge the Spanish Institute for Agricultural Research and Technology (INIA) and the European Regional Development Fund (FEDER) through the ECOINNOLI project (grant no. RTA2008-00024) and to the Andalusian Ministry of Innovation, Science and Enterprise through the MULTIOLI project (grant no. PAIDI P07-SEJ-03121) for their financial support in this research.

References

1 Anania, G. and D'Andrea, M.R.P. 2008. The Global Market for Olive Oil: Actors, Trends, Policies, Prospects and Research Needs. TRDEAG, FP VI Project. Working Paper 08/2. Available at Web site http://ageconsearch.umn.edu/bitstream/6109/2/wp080002.pdf (verified March 22, 2012).

2 Ruzevicius, J. 2008. The study of quality certification system of Lithuania. Engineering Economics 2:78–84.

3 Magd, H. and Curry, A. 2003. ISO 9000 and TQM: Are they complementary or contradictory to each other? TQM Magazine 15:244–256.

4 Sanz-Cañada, J. and Macías-Vázquez, A. 2005. Quality certification, institutions and innovation in local agro-food systems: Protected designations of origin of olive oil in Spain. Journal of Rural Studies 21:475–486.

5 Terlaak, A. and King, A.A. 2006. The effect of certification with the ISO 9000 quality management standard: A signaling approach. Journal of Economic Behavior and Organization 60:579–602.

6 Albano, G.L. and Lizzeri, A. 2001. Strategic certification and provision of quality. International Economic Review 42:267–283.

7 Ruttan, V.W. (ed.). 2003. Social Science Knowledge and Economic Development: An Institutional Design Perspective. University of Michigan Press, Ann Arbor, USA.

8 Luning, P.A. and Marcelis, W.J. (eds) 2009. Food Quality Management: Technological and Managerial Principles and Practices. Wageningen Academic Publishers, The Netherlands.

9 Caracuel-García, Á. 2004. Figuras, normas y protocolos de calidad como herramienta de mejora de la seguridad alimentaria. Anales de la Real Academia de Ciencias Veterinarias de Andalucía Oriental 17:229–245.

10 Lucena-Cobos, B., Cáceres-Clavero, F., Cruz-Gómez, J.C., and Méndez-Rodríguez, M.Á. 2004. Sistemas de certificación de la calidad en el sector agroalimentario español. Distribución y Consumo 76:23–39.

11 Maza, M.T., Sepúlveda, W.S., Campo, C.E., and Berga, A. M. 2010. Gestión de la calidad ISO 9001 en almazaras del sur de España. Revista LEBRET 1:117–130.

12 Kaldis, P.E. and Gardeli, C.J. 1999. Quality management in the agri-food sector. An interdisciplinary approach to the Greek apricot industry. In International Symposium on Apricot Culture. Acta Horticulturae (ISHS) 488:65–70. Available at Web site http://www.actahort.org/books/488/488_5.htm (verified March 28, 2012).

13 Rogers, E.M. and Shoemaker, F.F. (eds) 1971. Communication of Innovations: A Cross-cultural Approach. Free Press, New York.

14 FAO 2012. Food and Agriculture Organization of the United Nations. FAOSTAT. Available at Web site http://faostat.fao.org/DesktopDefault.aspx?PageID=339&lang=es (verified May 16, 2012).

15 MARM 2010. Anuario de estadística 2010. Ministerio de Medio Ambiente y Medio Rural y Marino. Parte tercera. Estadísticas del medio rural. Capítulo 13. Superficies y producciones de cultivos. Available at Web site http://www.magrama.gob.es/estadistica/pags/anuario/2010/AE_2010_Avance.pdf. (verified March 8, 2012).

16 MARM 2009. Anuario de estadística 2009. Ministerio de Medio Ambiente y Medio Rural y Marino. Parte tercera. Estadísticas del medio rural. Capítulo 13. Superficies y producciones de cultivos. Available at Web site http://www.magrama.gob.es/es/estadistica/temas/estad-publicaciones/anuario-de-estadistica/2009/default.aspx (verified March 8, 2012).

17 CAP 2012. Evolución macromagnitudes agrarias provinciales. 2005–2010. (Met SEC.95). Actualizado Febrero 2012. Consejería de Agricultura y Pesca. Junta de Andalucía. Available at Web site http://www.cap.junta-andalucia.es/agriculturaypesca/portal/servicios/estadisticas/estadisticas/agrarias/macromagnitudes-y-economia-agraria.html (verified March 6, 2012).

18 Gómez-Limón, J.A. and Arriaza-Balmón, M. 2011. Evaluación de la sostenibilidad de las explotaciones de olivar en Andalucía. XIII Premio unicaja de investigación agraria. Available at Web site https://www.unicaja.es/resources/1320671483909.pdf (verified March 20, 2012).

19 Junta de Andalucía 2002. El olivar andaluz. Unidad de Prospectiva de la Consejería de Agricultura y Pesca de la Junta de Andalucía y Empresa Pública de Desarrollo Agrario y Pesquero de Andalucía. Available at Web site http://www.cap.junta-andalucia.es/agriculturaypesca/prospectiva/Olivar4_doc_sinAnexo.pdf (verified November 22, 2011).

20 Parras-Rosa, M., Senise-Barrio, O., and Torres-Ruiz, F.J. 2003. Comercialización de aceites de oliva y concentración de la oferta: Estado de la cuestión. Boletín del Instituto de Estudios Giennenses 185:355–372.

21 Montegut-Salla, Y., Cristóbal-Fransi, E., and Marimon-Viadiu, F. 2007. Caracterización de las almazaras cooperativas catalanas: Análisis interno de la fase industrial o de transformación. Revista de Estudios Cooperativos 93:68–97.

22 Silva-Pérez, R. 2005. Agricultura y competitividad territorial en Andalucía. Estudios Geográficos 66:689–719.

23 Parra-López, C., Calatrava-Requena, J., and De Haro-Giménez, T. 2008. A systemic comparative assessment of the multifunctional performance of alternative olive systems in Spain within an AHP-extended framework. Ecological Economics 64:820–834.

24 CAP 2009. Guía de la producción integrada en Andalucía. 2009. Consejería de agricultura y pesca. Junta de Andalucía. Available at Web site http://compromisos20082012.junta-andalucia.es/archivos_repos/0/777.pdf (verified September 3, 2012).

25 Orellana, F.J., del Sagrado, J., and del Aguila, I.M. 2011. SAIFA: A web-based system for integrated production of

olive cultivation. Computers and Electronics in Agriculture 78:231–237.

26 CAP 2009. Anuario de estadísticas agrarias y pesqueras de Andalucía. Available at Web site http://www.cap.junta-andalucia.es/agriculturaypesca/portal/servicios/estadisticas/estadisticas/agrarias/resumen-anual.html (verified March 8, 2012).

27 CAP 2011. Estadística de producción integrada.. Evolución de la superficie total por cultivos entre el año 2003 y 2011. Available at Web site http://www.cap.junta-andalucia.es/agriculturaypesca/portal/export/sites/default/comun/galerias/-galeriaDescargas/cap/agricultura-ganaderia/agricultura/Sanidad-Vegetal/Produccion-Integrada-/Evolucion_superficie_produccion_integrada_2003_-_2011.pdf (verified March 8, 2012).

28 Marbán-Flores, R. 2004. Las denominaciones de origen y las etiquetas ecológicas impulsoras de estrategias de comercialización, basadas en la calidad, en las almazaras cooperativas de Castilla-La Mancha. Revista de Estudios Cooperativos 82:71–88.

29 Marbán-Flores, R. 2005. Principales estrategias de gestión de la calidad desarrolladas por las almazaras cooperativas amparadas en la denominación de origen Montes de Toledo. CIRIEC-España. Revista de Economía Pública, Social y Cooperativa 51:185–209.

30 Polelli, M., Corsi, S., and Giacomelli, P. 2007. Typical products and marketing strategies for Sicilian olive oils. In 103rd European Association of Agricultural Economists Seminar, April 23–25, Barcelona, Spain.

31 Sanz-Cañada, J. and Macías-Vázquez, A. 2008. Protected designations of origin and innovations: The olive oil branch in Sierra Magina (Andalusia). Cahiers Agricultures 17:542–546.

32 Roselli, L., Casieri, A., De Gennaro, B., and Medicamento, U. 2009. Olive oils protected by the EU geographical indications: Creation and distribution of the value-adding within supply chains. In 113th European Association of Agricultural Economists seminar: A resilient European food industry and food chain in a challenging world, September 3–6, Chania, Crete, Greece.

33 Baptista, A. and Biswas, P. 2010. Quality differentation as a strategy for the viability of traditional olive farming in Trás os-Montes region. In 116th European Association of Agricultural Economics Seminar: Spatial Dynamics in Agri-food Systems: Implications for Sustainability and Consumer Welfare, October 27–30, Parma, Italy.

34 Bonnet, C. and Simioni, M. 2001. Assessing consumer response to protected designation of origin labelling: A mixed multinomial logit approach. European Review of Agricultural Economics 28:433–449.

35 Fotopoulos, C. and Krystallis, A. 2001. Are quality labels a real marketing advantage? A conjoint application on Greek PDO protected olive oil. Journal of International Food and Agribusiness Marketing 12:1–22.

36 Van der Lans, I.A., Van Ittersum, K., De Cicco, A., and Loseby, M. 2001. The role of the region of origin and EU certificates of origin in consumer evaluation of food products. European Review of Agricultural Economics 28:451–477.

37 Espejel, J., Fandos, C., and Flavián, C. 2007. La importancia de las denominaciones de origen protegidas como indicadores de calidad para el comportamiento del consumidor. El caso del aceite de oliva del bajo Aragón. Economia Agraria y Recursos Naturales 7:3–19.

38 Martín-Cerdeño, V.J. 2009. Denominaciones de origen y de calidad diferenciada en el mercado alimentario español. Distribución y consumo 106:89–102.

39 Navarro-García, L., Ruiz-Avilés, P., Jiménez-Herrera, B., Barea-Barea, F., Penco-Valenzuela, J.M., and Vázquez-Cobo, A. 2010. La formación de los consumidores en la percepción de la calidad de los aceites de oliva. Reflexiones y estrategias para la valorización de los aceites de oliva virgen extra con DOP andaluces. Revista de Estudios Empresariales. Segunda Época 1:144–168.

40 Erraach, Y., Sayadi, S., Parra-López, C., Carmona-Torres, C., and Hinojosa-Rodríguez, A. 2011. Purchasing and consumption habits of consumers towards protected designation of origin (PDO) olive oil in Andalusia (Spain). In Olivebioteq 2011: International Conference for Olive Tree and Olive Products. October 31–November 4, Chania, Crete, Greece.

41 Ruiz-Avilés, P., Navarro-García, L., Barea-Barea, F., and Vázquez-Cobo, A. 2007. La calidad y las denominaciones de origen en los aceites de oliva andaluces. Distribución y consumo 96:42–50.

42 Ruiz-Castillo, B. 2008. Las denominaciones de origen protegidas y el aceite de oliva en España. Distribución y consumo 18:57–68.

43 Chinchilla-Fernández, M. 1999. Communication and innovation on the Andalusian olive sector. A special reference to organic farming. Final year dissertation, School of Advanced Agricultural Engineering Studies (ETSIAM). University of Cordoba, Spain.

44 Parra-López, C. and Calatrava-Requena, J. 2005. Factors related to the adoption of organic farming in Spanish olive orchards. Spanish Journal of Agricultural Research 3:5–16.

45 Parra-López, C. and Calatrava-Requena, J. 2006. Comparison of farming techniques actually implemented and their rationality in organic and conventional olive groves in Andalusia, Spain. Biological Agriculture and Horticulture 24:35–59.

46 Parra-López, C., De Haro-Giménez, T., and Calatrava-Requena, J. 2007. Diffusion and adoption of organic farming in the southern Spanish olive groves. Journal of Sustainable Agriculture 30:105–151.

47 Parra-López, C., Calatrava-Requena, J., and De Haro-Giménez, T. 2007. A multi-criteria evaluation of the environmental performances of conventional, organic and integrated olive-growing systems in the south of Spain based on experts' knowledge. Renewable Agriculture and Food Systems 22:189–203.

48 Gómez, J.A., Amato, M., Celano, G., and Koubouris, G.C. 2008. Organic olive orchards on sloping land: More than a specialty niche production system? Journal of Environmental Management 89:99–109.

49 Vilar-Hernández, J., Velasco-Gámez, M.M., and Puentes-Poyatos, R. 2011. Consequences of implanting a quality management system in olive oil manufacture: An international study. Agroalimentaria 15:69–86.

50 Marbán-Flores, R. 2003. Posibles estrategias comerciales para el desarrollo local y regional en la industria de la transformación del aceite de oliva: La región de Castilla-La Mancha. Problemas del Desarrollo 34:49–64.

51 Moyano-Fuentes, J., Bruque-Cámara, S., and Sacristán-Díaz, M. 2002. Calidad y subsistema productivo en la industria agroalimentaria. Un estudio empírico aplicado al cooperativismo oleícola. Revista Española de Estudios Agrosociales y Pesqueros 194:49–69.

52 Krystallis, A. and Ness, M. 2005. Consumer preferences for quality foods from a south European perspective: A conjoint analysis implementation on Greek olive oil. International Food and Agribusiness Management Review 8:62–91.

53 Galluzzo, N. 2007. Prospects of development of quality olive oil for Italian farms: First indications in a case of study on a focus group. In 105th European Association of Agricultural Economists seminar: International Marketing and International Trade of Quality Food Products, March 8–10, Bologna, Italy.

54 Menapace, L., Colson, G., Grebitus, C., and Facendola, M. 2008. Consumer preferences for extra virgin olive oil with country-of-origin and geographical indication labels in Canada. In American Agricultural Economics Association Annual Meeting, July 27–29, Orlando, Florida. (New Name 2008: Agricultural and Applied Economics Association).

55 Hinojosa-Rodríguez, A., Parra-López, C., Carmona-Torres, C., and Sayadi, S. 2011. Certified quality systems and good practices in the olive farming sector of Andalusia, Spain: Special focus on protected designation of origin. In 5th International European Forum (Igls-Forum) on System Dynamics and Innovation in Food Networks, February 14–18, Innsbruck-Igls, Austria. Contributed paper, oral presentation.

56 IEA 2012. Instituto de Estadística y Cartografía de Andalucía. Anuario Estadístico de Andalucía 2012. Principales producciones agrícolas por provincia. Años 2009–2010. Available at Web site http://www.ieca.junta-andalucia.es/anuario/anuario12/anuario12c06.htm#c285 (verified March 12, 2012).

57 IEA 2012. Instituto de Estadística y Cartografía de Andalucía. Anuario Estadístico de Andalucía 2012. Superficie dedicada a cultivos por provincia. Años 2009–2010. Available at Web site http://www.ieca.junta-andalucia.es/anuario/anuario12/anuario12c06.htm#c285 (verified March 12, 2012).

58 CAP 2008. El sector del aceite de oliva y de la aceituna de mesa en Andalucía 2008. Consejería de Agricultura, Pesca y Medio Ambiente. Junta de Andalucía. Available at Web site http://ws128.juntadeandalucia.es/agriculturaypesca/portal/servicios/estadisticas/estudios-e-informes/agricultura/olivar/sector-aceite-aceituna-mesa-andalucia.html (verified March 8, 2012).

59 Barranco, D. 2008. Variedades y Patrones. In: Barranco, D, Fernández-Escobar, R, and Rallo, L. (eds). El cultivo del Olivo. 6th ed. Ediciones Mundi, Madrid and Junta de Andalucía, Sevilla. p. 63–92.

60 Padilla, C., Villalobos, P., Spiller, A., and Henry, G. 2007. Consumer preference and willingness to pay for an officially certified quality label: Implications for traditional food producers. Agricultura Tecnica 67:300–308.

61 Ruttan, V.W. and Hayami, Y. 1984. Toward a theory of induced institutional innovation. Journal of Development Studies 20:203–223.

62 Djekic, I., Tomasevic, I., and Radovanovic, R. 2011. Quality and food safety issues revealed in certified food companies in three Western Balkans countries. Food Control 22:1736–1741.

63 Mutersbaugh, T. 2005. Just-in-space: Certified rural products, labor of quality, and regulatory spaces. Journal of Rural Studies 21:389–402.

64 Jatib, I. 2003. Food safety and quality assurance key drivers of competitiveness. International Food and Agribusiness Management Review 6:38–56.

65 Juntunen, E. and Salo, S. 1997. Use of the ISO 9002 quality standard model in strawberry farming. In Third International Strawberry Symposium. Acta Horticulturae (ISHS) 439:429–432. Available at Web site http://www.actahort.org/books/439/439_71.htm (verified May 14, 2012).

66 Karipidis, P., Athanassiadis, K., Aggelopoulos, S., and Giompliakis, E. 2009. Factors affecting the adoption of quality assurance systems in small food enterprises. Food Control 20:93–98.

67 Kourouxou, M., Siardos, G., Iakovidou, O., and Kalburtji, K. 2008. Organic farmers in islands: Agricultural management and attitude towards the environment. International Journal of Sustainable Development and World Ecology 15:553–564.

68 Fan, H.P., Ye, Z.H., Zhao, W.J., Tian, H.S., Qi, Y.M., and Busch, L. 2009. Agriculture and food quality and safety certification agencies in four Chinese cities. Food Control 20:627–630.

Renewable Agriculture and Food Systems: 29(4); 310–318 doi:10.1017/S1742170513000161

Comparative carbon footprint assessment of winter lettuce production in two climatic zones for Midwestern market

Rachel Plawecki[1], Rich Pirog[1,2], Adam Montri[3] and Michael W. Hamm[1,2,4,5*]

[1]Department of Community, Agriculture, Recreation and Resource Studies, Michigan State University, East Lansing, MI 48824, USA.
[2]Center for Regional Food Systems, Michigan State University, East Lansing, MI 48824, USA.
[3]Department of Horticulture, Michigan State University, East Lansing, MI 48824, USA.
[4]Department of Plant, Soil and Microbial Sciences, Michigan State University, East Lansing, MI 48824, USA.
[5]Department of Food Science and Human Nutrition, Michigan State University, East Lansing, MI 48824, USA.
*Corresponding author: mhamm@msu.edu

Accepted 10 April 2013; First published online 21 August 2013 **Research Paper**

Abstract

The following study assesses cold-season hoop house lettuce production in the context of local food systems' relative environmental effects. For this purpose, we compare the carbon footprints of leaf lettuce production in two climatic zones, one close to the consumer market and one distant, via environmental impact modeling in SimaPro 7.3. A site-specific scenario is first detailed with organic leaf lettuce locally grown in an East Lansing, Michigan hoop house. This is compared to a hypothetical scenario, modeled using average industry data, with leaf lettuce conventionally grown in California then shipped to East Lansing. The system boundaries used in this analysis extend from manufacturing of farm production inputs to a hypothetical retail gate. We assumed that the consumer drove the same distance to the retailer in each case. The functional unit used is 1 kg of leaf lettuce. Results demonstrate that the distant system exhibits 4.3 times the CO_2 'footprint' per kg of lettuce. This nonlocal system also resulted in higher resource depletion, health impact and ecological damage potential as demonstrated via the SimaPro simulation. This study concludes that unheated, hoop house lettuce production, given the assumption on within-area travel, has a smaller carbon footprint than outdoor, distant production, and speaks to both the potential value of more localized food systems and the need for a more diverse set of scenario modeling to understand the boundaries of this value.

Key words: hoop house, lettuce, local, Midwest, carbon footprint, winter

Introduction

As worldwide participation in efforts combating climate change and rising CO_2 emissions expands, there is increasing recognition of the need to encourage consumer food choices that are environmentally sound. However, within this framework of consumer choice there is a constant tug in the popular literature between focusing on a seasonal, local diet[1,2] or more simply on a healthier diet with a greater preponderance of fruits and vegetables[3]. Developments in post-harvest management, breed development, refrigeration and other strategies have made it feasible to generate out-of-season, fresh produce from anywhere for anywhere. Consumers have largely come to expect, demand and feel entitled to this pristine produce. The complex and lengthy supply chains necessary for year round access are particularly relevant in the colder regions of the US, where winter weather seemingly prevents sustainable, local production of fresh fruits and vegetables. National and international produce sourcing has raised environmental concerns about the purely nutrition-focused diet.

The 'eat local' movement has gained significant strength in the past 15 years, often in the name of environmental soundness especially centered on the notion of 'food miles'. However, this notion is itself contested, as not only the miles but the efficiency of transportation per unit of food is also a consideration in analyzing C-footprints—or overall carbon emissions. Also, the focus on 'localization' does not necessarily account for the food production method or the choice of food items (i.e., the overall food on the plate) in one's

© Cambridge University Press 2013

diet. One study reported that 83% of the greenhouse gas (GHG) emissions from US food supply are derived from the production phase, while only 11% stem from transportation[4]. This same study estimated that buying all local foods would only reduce GHG emissions from an average diet by 4–5%, suggesting that the best reduction strategy lies in food product choice[4].

As this debate continues, life cycle assessment (LCA) as 'a technique to assess the environmental aspects and potential effects associated with a product, process, or service, by compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental effects associated with identified inputs and releases; and interpreting the results to help [make] a more informed decision' has become an increasingly important tool for identifying strategies and system components for improvement[5]. As reviewed by Saunders et al., most of the early studies conducted using 'food miles' compare only transportation emissions between local and imported foods, while a thorough LCA involves quantification of both production and transportation effects through its 'cradle to grave' analytical approach, providing a more robust comparison of similar food products[6]. This study, while utilizing LCA's 'cradle-to-grave' framework and a leading LCA software package, takes an approach focusing on carbon footprint rather than an overall environmental impact analysis in the hope of capturing relative contributions to climate change.

Few LCAs of fruits and vegetables have been conducted worldwide. A nearly cradle-to-grave study performed in Germany comparing domestic to imported apples found imported apples to contain higher embedded energy[7]. Carrots produced locally in Sweden were found to incur fewer GHGs than when imported[8]. However, Swedish tomato production demonstrated a reverse locational effect with local tomatoes incurring higher GHGs primarily due to differences in greenhouse heating efficiency[8]. Another study compared salad crop production for UK markets, finding that importation from Spain demonstrated a lower global warming potential (GWP) than indoor production in the UK, but a higher GWP than outdoor UK production[9].

Lettuce production and consumption is particularly interesting to study since 98% of US lettuce consumed is sourced from domestic production, nearly all of which occurs in California and Arizona[10], and thus large amounts of lettuce are routinely shipped across the country. This will probably increase in the absence of fundamental production-location change as per capita leaf lettuce consumption has been increasing in the past decade[10].

One LCA of lettuce's environmental footprint has been conducted to date in a European context[11]. The analysis compared GHG emissions of summer UK field-grown lettuce production, winter UK heated greenhouse production and summer and winter field-grown lettuce production in Spain. All were modeled based on UK consumption. Locational effects on GHG emissions were consistent with research on other produce, where local systems proved more favorable to importation except when using a heated greenhouse[8,9].

Recognizing that energy inputs in greenhouse systems contribute substantially to any analysis of local off-season production in cold climates, there has been significant work in the US to develop unheated hoop house systems for winter production of certain vegetables. This began with the work of Eliot Coleman[12] and has been significantly expanded with peer-reviewed research[13]. One earlier study compared energy use by tomato cropping systems in varying climates without regard to transportation, finding that highly mechanized field production in California utilized 7.5 times less energy per hectare than Israeli hoop house tomato production[14]. However, to date there has been no analysis to determine if hoop houses represent advancement from an environmental footprint standpoint over cross-country importation in production of crops that are fairly cold tolerant and do not require supplemental light. We therefore present a carbon footprint assessment of two different methods/locations of lettuce production, incorporating both the production and transportation footprints. The production methods include an organic hoop house production system in Michigan, USA and that of open-field, conventional production in a southwestern US desert climate. Hoop houses, structures made of plastic or metal pipe and covered with plastic or other sheeting, present an interesting mode of production because they do not incur the same heating costs as conventional greenhouses yet are capable of producing a variety of winter crops. We hypothesized that due to reduction in energy for heating in winter production these structures could be environmentally advantageous relative to long-distance importation.

Methods

Site and product dependency

Agricultural LCA results are highly site-dependent[8]. Comparisons between food types are particularly difficult given differences in production methods and boundary conditions for analysis. For example, GHG emissions from fruit and vegetable production/distribution vary drastically from others, such as cereals or products associated with trophic magnification like meat and dairy[4]. In part because of wide variations in production inputs and shipping mechanisms for each crop or food product and in part due to the relative paucity of a robust set of LCAs across crop types, it is necessary to individually assess effects rather than extrapolating results from another crop. The same principle applies to geographical locations. The study detailed here significantly contributes to this growing dataset of agricultural LCAs by comparing the environmental effects of unheated winter lettuce

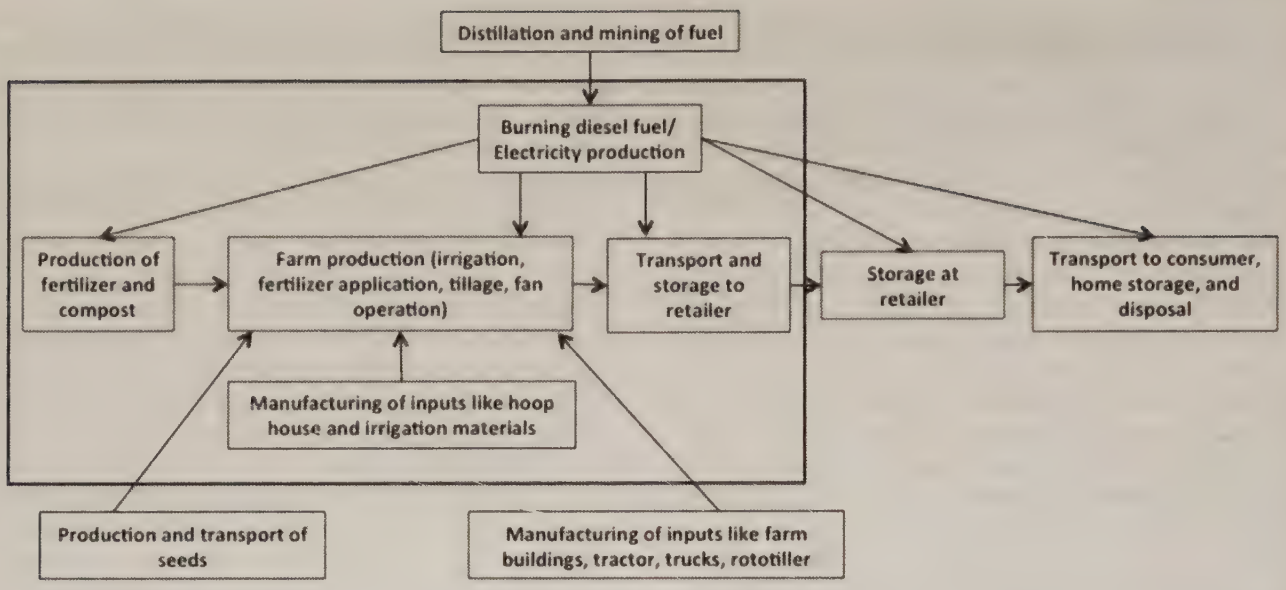

Distillation and mining of fuel
Burning diesel fuel/ Electricity production
Production of fertilizer and compost
Farm production (irrigation, fertilizer application, tillage, fan operation)
Transport and storage to retailer
Storage at retailer
Transport to consumer, home storage, and disposal
Manufacturing of inputs like hoop house and irrigation materials
Production and transport of seeds
Manufacturing of inputs like farm buildings, tractor, trucks, rototiller

Figure 1. System boundaries of the carbon footprint analyses of leaf lettuce produced in a Michigan hoop house and California desert (thick line).

production in cold and warm climates to supply a cold climate market. Thus, the sustainability of outdoor and hoop house lettuce production—as components of a supply chain complete to retail outlet—are evaluated using two International Standards Organization (ISO)—compliant environmental impact assessment methods (GHG Protocol and Eco-Indicator 99).

System boundaries

The system boundaries for this study encompass manufacturing of building materials and fertilizers through transportation of lettuce to the retailer (Fig. 1). More specifically, effects are calculated for the following:

- Manufacturing and transportation of the hoop house structure
- Manufacturing of the fertilizer (or compost in the Michigan case), including fuel and electricity use
- Manufacturing of irrigation materials, including fuel and electricity use
- Fertilizer application
- Use of agricultural machinery for land preparation (tractor for outdoor; rotary cultivator for indoor), including fuel use
- Electricity use in the hoop house (e.g., for automatic ventilation, irrigation)
- Irrigation, including water use and electricity
- Processing, transportation and storage of lettuce between the farm and the retailer

Excluded in the study are effects resulting from upstream processes such as manufacturing of agricultural machinery, seeds, lorries or passenger cars. Downstream processes not included are: storage at the retailer, transportation of lettuce from retailer to consumer, home storage and use and waste scenarios—the assumption being made that these will simultaneously be identical independent of product source and extremely variable based on location of consumer to retailer as well as transportation patterns of the consumer. For example, one study showcased this uncertainty in the emissions from the final retailer to consumer transport, demonstrating that it could range from 0 g CO_2 per kg of food (if the consumer walks) to 12.1 kg CO_2 per kg food (if the consumer drives 15 km for the sole purpose of shopping)[15]. Other studies have excluded final transport due to this variability in mode of transport, vehicle fuel efficiency and number of items in the consumer's hypothetical shopping cart[8].

Strategies and assumptions in cold-climate hoop house production scenario

We modeled this system using the hoop house most frequently recommended by the staff at Michigan State University's (MSU) Student Organic Farm (A. Montri, personal communication, October 2010; J. Biernbaum, Michigan State University, personal communication, October 2010), a 30′ × 96′ (9.14 m × 29.26 m) steel, aluminum and wood frame with a double layer of polyethylene film. The Student Organic Farm hosts four houses of this exact type for research and production purposes, and the MSU Extension team assists in building this type of house across Michigan, making this assumption particularly relevant. One of the hoop houses produces greens for a campus dining hall through the winter. Data describing the weight of the hoop house structure's components (steel, polyethylene and aluminum) were provided by the manufacturer. These weights were then amortized over the material's projected life span: the steel (1817.09 kg) and aluminum (65.3 kg) used in the hoop house frame are

assumed to have 40-year life spans, the polyethylene film (65.3 kg) used to cover the hoop house is assumed to have a 4-year life span, while the pine boards used as the structure's base posts are assumed to have a 10-year life span (A. Montri, personal communication, October 2010). The inflation fan used to separate the two layers of polyethylene film is assumed to run constantly. The specifications for the fan's electrical use were found on the manufacturer's website[16]. Fuel use during transportation of the hoop house to the farm was estimated using the location of the manufacturer and was adjusted for a 40-year structural life span and full truckload.

Hoop house input, timing of production, yields, etc. were provided by field experts based on their experiences with these systems (A. Montri, personal communication, October 2010; J. Biernbaum, Michigan State University, personal communication, October 2010). The first lettuce crop was assumed transplanted into the hoop house in East Lansing, Michigan on September 18 and harvested in early December. The second crop was planted in early February and harvested in early April, with each harvest yielding 4000 heads for a total of 8000 heads during the Michigan off-season (A. Montri, personal communication, October 2010). This yield is the result of planting 70% of the hoop house area with plants in 8″ × 8″ squares.

The leaf lettuce was assumed irrigated every 7–10 days between 10.00 hours and 14.00 hours using a drip irrigation system. The irrigation system included the PVC pipeline and a frost-free hydrant (J. Biernbaum, Michigan State University, personal communication, October 2010). Water use was estimated as: $1.18\,m^3\,week^{-1}$ between September and December, $0.47\,m^3\,week^{-1}$ between February and March, and $1.18\,m^3\,week^{-1}$ during the first week of April (A. Montri, personal communication, October 2010).

The only land preparation in this scenario was tilling the $185.8\,m^2$ planted area by rototiller four times over the course of the season; the estimated time was 2 h and gasoline use for this period was included (A. Montri, personal communication, October 2010). The only soil amendment used in this scenario was compost, produced at a nearby facility rather than at the farm itself. Emissions from transporting compost to the site are not calculated, nor are tractor emissions from application. This study does not calculate emissions from pest management techniques.

It should be noted that while this hoop house is presumed to only produce leaf lettuce, this is not realistic. Diversified production is much more common on farms of this sort. This assumption was made to simplify the comparison process between production methods.

Strategies and assumptions in warm climate production scenario

Data for the warm climate (California) production process was primarily based on two previously compiled reports on southwestern lettuce production[17,18].

Leaf lettuce in this scenario was produced on two 121-hectare land plots in California. The first crop was grown in Imperial County, California between mid-September and early December[17]. The second crop was grown in the Central Valley region of California between late December and early April[17]. These planting to harvest lengths are close to the suggested 130-day growing period for this region and time of year. The marked geographical difference complicates the impact analysis only with respect to irrigation levels, discussed below. Reported leaf lettuce harvest in the southwestern US during the winter varies between 51,900 and 66,700 heads per hectare. We assumed a 59,300 heads per hectare yield, amounting to 14.4 million heads in total over the course of the season. The farm production is assumed to use conventional practices including pre-irrigation prior to cultivation. The crop was hand-weeded after 30 days and again after 45–50 days of growth[17].

Electricity use and manufacturing costs associated with irrigation are contained within the 'Irrigating' process of SimaPro 7.3's US EcoInvent 2.2 database used for this analysis. Industry average water use data suggests a total of $7619.98\,m^3\,hectare^{-1}$ for leaf lettuce production in Imperial County, California and a value of $9144.00\,m^3\,hectare^{-1}$ for Central Valley, California[17]. Thus, the average of the two values was taken, and water use of $8381.99\,m^3\,hectare^{-1}$ was assumed.

Average industry data suggest that $280.2\,kg\,hectare^{-1}$ of phosphorus fertilizer and $250.1\,kg\,hectare^{-1}$ of nitrogen fertilizer are applied to leaf lettuce crops in this region[19]. Fertilizer manufacturing is accounted for in the SimaPro database, including industry-average models of fertilizer transportation from storehouse to farm.

Diesel use during land preparation is based on the 1996 UC study on loose-leaf lettuce production[18]. Excluding the use of machinery for pesticide application, they calculated 32.79 machine-hours per hectare during the first production cycle (September to December) and 3.81 machine-hours per hectare during the second production cycle (January to April). A 200 horsepower 4-wheel drive tractor performed plowing, ripping, stubble disking, disking and listing beds prior to the first crop's seeding. After seeding, this tractor spread the fertilizer. During the second production cycle, the only use for the tractor was in disking and fertilizing.

Energy use during lettuce processing and storage was quantified based on a 2005 study comparing the energy requirements embedded in local versus imported apples[7]. The authors' recommendation for the energy requirement of initially cooling apples is $0.086\,MJ\,kg^{-1}$. The apples' cooling process is assumed to be comparable to the customary initial vacuum cooling stage for US leaf lettuce, and is so applied (as 0.043 MJ per head). The authors also recommend the energy use of a refrigerated truck at $0.3\,MJ\,t^{-1}\,km^{-1}$ ($0.055\,MJ\,kg^{-1}$). This study adopts this value and considers it a contribution to transportation energy requirements. A 2008

LCA of European salad crop production cites this same total processing and storage energy contribution ($0.141\,MJ\,kg^{-1}$ or $35.5\,kWh\,ton^{-1}$ lettuce) in the case of the study's most efficient observed farm[9]. Since the authors caution against citing this direct farm measurement alone, the apple study is considered a validation of the $0.141\,MJ\,kg^{-1}$ value.

The leaf lettuce was transported 3605 km directly from the farm in southern Central Valley California to the retailer in mid-Michigan. Since this is a simplification of real-life vegetable supply chains, it probably underestimates the distance traveled. A >32-ton lorry is assumed to carry a 35-ton truckload of leaf lettuce to the retailer[19]. The route taken by the truck after the initial drop-off incurs a great deal of uncertainty, and is therefore omitted. The implications of these transportation assumptions are further discussed in the results of this study.

Results

The carbon footprint analyses were conducted using impact assessments within SimaPro 7.3. This software is designed to conduct impact assessments using four basic steps, although the last three are optional and depend on the assessment method[20]. The first, characterization, determines which substances contribute to an impact category (e.g., acidification) and at what level. The next, damage assessment, combines impact categories into damage categories (e.g., adding respiratory inorganics and carcinogens to human health damage). Normalization compares the impact contributions to some specified reference impact; this study skipped the normalization step. Lastly, weighting applies weighting factors to each category in order to obtain a total or overall impact score.

SimaPro 7.3 was chosen for its inclusion of the US-EI 2.2 database, which reports EcoInvent 2.2 industrial data using US electrical production as opposed to European. Also, the EcoInvent 2.2 and US-LCI databases have a wide selection of agricultural data. Impact assessments were performed using the GHG Protocol and Eco-Indicator 99 methods. Though the focus of this study is on the production methods' contribution to climate change, other impact categories are used to verify the results of environmental impact rankings.

Throughout the analysis one head of leaf lettuce is assumed to weigh 0.5 kg. Results of the impact assessments performed within SimaPro 7.3 are reported in terms of this study's functional unit: 1 kg of leaf lettuce. It should be kept in mind that lettuce yields, fertilizer use and irrigation requirements are specific to the soil type and temperature characteristics of mid-Michigan and the southern deserts of California as well as precipitation levels in California. Also, the results of this study are largely only applicable to leaf lettuce and crops with similar growing requirements and yields.

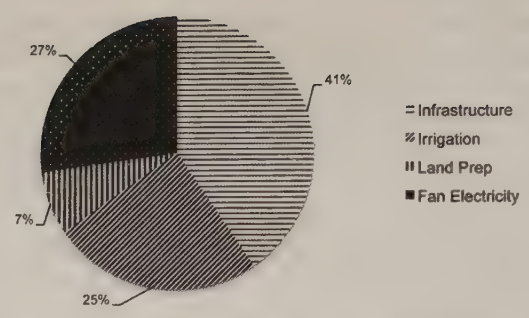


Figure 2. Contribution to hoop house emissions by stage.

GHG protocol

The GHG Protocol, while not a full life cycle impact assessment method, is the most widely used GHG accounting tool in the world, both in academic and private sectors. Since this study's focus is on overall carbon impact, GHG Protocol was the appropriate framework for analysis. The results are reported in kg CO_2 per unit.

Hoop house impact assessment. Producing 1 kg of leaf lettuce using an unheated greenhouse, with the system conditions outlined earlier, results in emissions of 0.198 kg CO_2. The largest contributor to this impact stemmed from the energy embedded in the hoop house structure (Fig. 2). 23.2% of total emissions came from the steel framework, and 8.31% from transport of the house from Georgia to Michigan (adjusted for a 6-house load and a 40-year life span). The hoop house framing and plastic film were of less importance, accounting for 2.58% and 5.24%, respectively. Irrigation, namely PVC pipes with 14.9% of irrigation's total 24.8% emissions contribution, and fan electricity played roughly equal parts in the impact assessment. Almost 90% of 7.45% for land preparation emissions originated with compost production rather than rototiller usage.

Outdoor impact assessment. Producing 1 kg of lettuce in California according to the previously described method then shipping it to Michigan results in emission of 0.857 kg CO_2. The final transport of lettuce to Michigan, which includes lorry operation, diesel use and refrigeration accounts for over three-quarters of this value. 48.2% of total emissions came from truck use, while 29.5% of the total came from refrigeration electricity. These values are most likely underestimates of the true values, as the supply chain assumed here was simplified to exclude diversions to regional hubs. Also, over three-quarters of the land preparation emissions stemmed from nitrogen fertilizer production and application. Tractor use thus represents a very small portion of the overall system emissions. A summary of the major process contributions is illustrated in Fig. 3.

Production comparison. Total emissions from California production were 4.3 times those of the hoop house production in Michigan (Table 1). In fact,

Table 1. Carbon emission comparison.

Source of emissions	Hoop House, kg CO_2	California, kg CO_2
Land prep	0.0148	0.0982
Irrigation	0.0492	0.0727
Fan electricity	0.0538	–
Vacuum cooling	–	0.0201
Infrastructure	0.0802	–
Truck refrigeration	–	0.253[1]
Transport (other)	–	0.413[1]
Total (per kg)	**0.198**	**0.857**

[1] California's impact assessment displays these emissions as one 'Transport' category. Numbers are separated here to highlight refrigeration contribution.

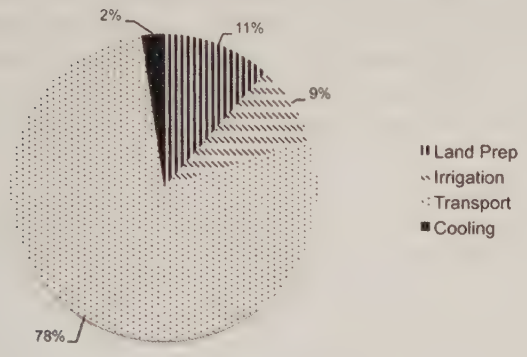


Figure 3. Contribution to California emissions by stage.

emissions from refrigerated transport were greater than that of the entire Michigan hoop house system. These two systems exhibited comparable irrigation-related emissions: 0.073 kg CO_2 in the California scenario and 0.05 kg CO_2 in the Michigan scenario. Comparing all other production stages, the Michigan hoop house scenario was found to have a smaller carbon footprint (Table 1). In the case of added electricity, the energy needed to continuously run the hoop house fan was about one-fifth of the energy needed to vacuum cool and refrigerate the lettuce during shipment. SimaPro's 'Lorry operation' process represented 48.2% of the California system emissions, but only 5.15% of the hoop house system. In real terms, the per kg emissions due to lorry operation from California to Michigan was 25 times that of the lorry operation for hoop house delivery from Georgia to Michigan amortized over a 40-year span.

Results could be altered by future additions of packaging effects. One head of local, hoop house lettuce is typically packed in a single food grade plastic bag, while shipped lettuce would be packed in a 24-heads per waxed cardboard box. While the packaging regimen is assumed to be negligibly different with respect to overall carbon footprint it would increase the nominal value of each system's emissions.

Eco-Indicator 99

The EI '99 analytical method takes a 'damage-oriented' approach and evaluates a 'product or process' sustainability based on the damages it causes in each of three categories: human health, ecosystem quality and resources. The first, human health, measures the years of life lost due to resource use or emissions related to the product (Disability Adjusted Life Years or DALYs). Damage is a function of carcinogens, respiratory inorganics and organics, climate change, radiation and ozone layer depletion[20]. Ecosystem quality measures, through ecotoxicity and acidification/eutrophication, species loss within a specified area over a certain period of time. 'Resources' measures the energy necessary for future extraction of fossil fuels and minerals that must compensate for the overuse of resources today[20]. Damages are weighted according to the hierarchist perspective, a long-term perspective that weights equally present and future damages. As such, ecosystem quality is weighted at 40%, human health at 30% and resources at 30%[21]. The results are reported as both (1) weighted collective damage attributed to each production stage and (2) weighted damage per impact category caused by each production method.

Resource depletion, over 90% of which is fossil fuel use, was the most significant source of ecological damage in the hoop house case, whether this was from truck diesel use, electrical grid powering or rototilling. The most environmentally damaging production stage was, as the first impact assessment method predicted, construction of the hoop house. Power generation and diesel consumption emitted high levels of respiratory inorganics emissions, contributing to the majority of human health effects especially within the infrastructure stage.

The most environmentally damaging stage in the California supply chain was transportation. This was mostly due to fossil fuel consumption (Resources) and its ensuing respiratory inorganics emissions, climate change impact and carcinogenic effects (Human Health). Tractor use and power generation translated into similarly distributed categorical effects within land preparation and irrigation. However, transportation's eco-factor points in this assessment were roughly five times larger than any other stage. Cooling had a negligible impact on this assessment.

Not surprisingly, the distant, outdoor lettuce production exhibited higher eco-factor points than the local, hoop house lettuce production in every impact category, though the relative importance of each category remained consistent between production methods (Fig. 4). It is notable that the top four impact categories all relate to transportation. This is consistent with the first impact assessment, where transportation was the key production stage, and distant, outdoor production was more environmentally damaging per kg of lettuce.

When comparing the scenarios by damage assessment category, the distant, outdoor system incurs over four

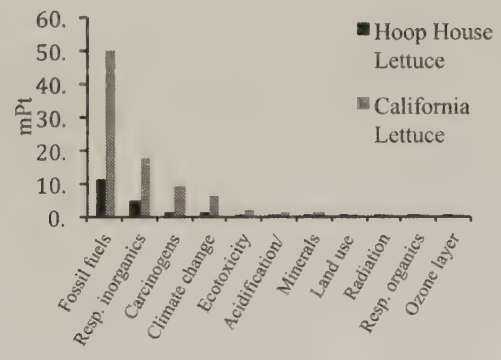


Figure 4. Comparison of EI '99 by impact category for winter lettuce production.

times the damage the local, indoor system does (89.11 mPt versus 21.10 mPt). Though the difference in 'ecosystem quality' is slight, the differences in 'resources' and 'human health' are substantial.

Discussion

This study provides a cogent analysis of two production systems—one outdoor at a distance to the consumer and one indoor in proximity to the consumer. In these analytical frameworks it is always a challenge to define the boundary conditions in such a way that the analysis is rigorous yet achievable. We purposefully did not include travel of the consumer to the point of purchase. One UK study sought to find the distance a consumer must drive to a farm such that the per unit carbon emissions were greater than that of a large-scale vegetable box delivery system that included packaging and cold storage (without regard to production method)[22]. The results illustrated that as long as the consumer did not drive more than 7.4 km (4.6 miles) to the farm, the system was more environmentally friendly than the box system.

In the research reported here, although transportation from retailer to consumer is not included within this study's system boundaries, we did conduct a simple hypothetical scenario using the GHG Protocol method to gauge the significance of a potential expansion in miles driven on the overall environmental impact. A process was added to each system that models a 5-mile (one way) shipment of 1 kg of lettuce in a passenger car (with no other groceries purchased or ancillary stops during the trip). Under this scenario, the discrepancy between distantly-produced and locally-produced fossil CO_2 equivalents was the same as before the process was added. However, if the locally-produced lettuce travels one mile farther than the distantly-produced lettuce, the overall impact is then greater by at least 0.05 kg CO_2 (4.3 kg versus 4.25 kg). The fossil fuel use (Eco-Indicator 99) is also pushed above the distantly-produced value. This implies a strong impact of consumer decisions over transportation routes, multiple use trips and sourcing decisions relative to overall system sustainability. Removing this influence enabled a clearer and more convincing comparison between upstream emissions associated with each production method.

The cold-climate model contains particularly sensitive assumptions that, when adjusted, are likely to affect the overall production system impact. For instance, the electricity mix modeled in SimaPro is an average US mix of 44% coal. Since Michigan's electricity mix utilizes closer to 66% coal, the electricity contributions (from irrigation and fan operation) are probably higher than reported. However, as the fan would probably not be running during production breaks, the reported numbers are slightly inflated. Even if the electricity contributions were doubled from 0.074 to 0.148 kg CO_2 the overall local system emissions would still not compare to the distant systems. Also, since the steel framework accounted for a quarter of the overall impact, more efficient manufacturing techniques could significantly alter the local systems' emissions. Location of production (i.e., sourcing a more local hoop house) would have a less significant effect since the hoop house's transport contributed only 8% of emissions.

Nonetheless, the results here provide a firm basis for considering greater scale off-season production in unheated hoop house systems close to points of consumption. Even considering a worst-case scenario for hoop house emissions, shipping conventionally grown leafy greens to cold-climate areas appears to incur greater environmental effects than a local system, given sufficient distance. A simple calculation reveals that the conventionally grown leafy lettuce incurs greater system-wide emissions at farm–retail transport distances above 37.9 km, assuming that the consumer drives the same distance to retail in both conventional and local cases in an 'average' vehicle. This indicates that conventional lettuce production, only when part of a truly localized supply chain, would incur fewer kg CO_2 per hectare. This result is consistent with both the UK lettuce seasonality study, as it found local field-grown lettuce to incur fewer GHG emissions than imported lettuce[11], and a study finding imported apples to contain higher embedded energy than domestic apples[7].

However, this study contradicts a recent Belgian report arguing that the processing, storage and transport of cabbage lettuce (among other products) have a higher carbon footprint as part of a local food system than a mainstream food system[15]. Their results, though they do not include the final transport from retailer to consumer, would suggest that these stages have a higher carbon footprint in a non-conventional supply chain. In comparing the transport and cooling stages of the distant, outdoor system with the local, hoop house transport process in the Michigan system, the distant, outdoor system is worse by a margin of 0.650 kg CO_2 per head of lettuce. Also, the Weber and Matthews study presented earlier suggested that the transportation emissions for

fruits and vegetables were a very minor value compared to GHG emissions from production[4]. As 77.7% of the distant, outdoor system emissions were the result of transportation, this study clearly contradicts that result in cases of leaf lettuce and crops with similar production footprints. In sum, this study found the percent of total emissions due to transport to be higher than previous studies, but the end result of a local food system having lower carbon footprint (except in the case of production in a heated greenhouse) is generally consistent with other research[8,9,11].

As for the 'eating local' debate, this study supports the claim that production location can be a key determinant of a supply chain's sustainability (at least with respect to environmental components and dependent on product type), but it is important to incorporate production methods within the system analyzed. It is also clear, however, that transportation issues between the retail space and the home can play a major role in tipping the balance on environmental sustainability indicators.

Conclusion

The results of this study suggest that unheated, hoop house lettuce production has less environmental impact, (and in particular carbon footprint) than outdoor, distant production, and speaks to the potential value of more localized food systems. Still, hoop house sustainability could possibly be improved by cleaner steel manufacturing or possibly by replacing steel with plastic or biobased materials. This requires more research. Although the physical and economic feasibility of large-scale hoop house production remains to be quantified, this study has demonstrated that hoop houses should be included in any discussion about reducing carbon footprints by sourcing appropriate produce locally during the winter.

References

1 Pollan, M. 2006. The Omnivore's Dilemma: A Natural History of Four Meals. Penguin Press, New York.

2 Smith, A.D., MacKinnon, J.B., and Smith, A. 2007. The 100-mile Diet: A Year of Local Eating. Vintage, Canada.

3 United States Dept. of Health and Human Services, United States Dept of Agriculture, United States Dietary Guidelines Advisory Committee. 2010. Dietary Guidelines for Americans, 2010. HHS publication, vol no HHS-ODPHP-2010-01-DGA-A, 7th ed. G.P.O., Washington, DC.

4 Weber, C.L. and Matthews, H.S. 2008. Food-miles and the relative climate impacts of food choices in the United States. Environmental Science and Technology 42 (10):3508–3513.

5 United States Environmental Protection Agency. 2006. Life Cycle Assessment: Principles and Practice. National Risk Management Research Laboratory, Cincinnati, Ohio.

6 Saunders, C., Barber, A., and Taylor, G. 2006. Food miles-comparative energy/emissions performance of New Zealand's agriculture industry. Lincoln University, Christchurch, New Zealand. Available at Web site http://www.lincoln.ac.nz/documents/2328_rr285_s13389.pdf (accessed June 25, 2013).

7 Blanke, M. and Burdick, B. 2005. Food (miles) for thought-energy balance for locally-grown versus imported apple fruit. Environmental Science and Pollution Research 12 (3):125–127.

8 Carlsson-Kanyama, A. 1998. Food consumption patterns and their influence on climate change: Greenhouse gas emissions in the life-cycle of tomatoes and carrots consumed in Sweden. Ambio 27(7)528–534.

9 Canals, L.M., Muñoz, I., Hospido, A., Plassmann, K., McLaren, S., Edwards-Jones, G., and Hounsome, B. 2008. Life Cycle Assessment (LCA) of Domestic vs. Imported Vegetables. Case Studies on Broccoli, Salad Crops and Green Beans. Centre for Environmental Strategy, University of Surrey, UK. Available at Web site http://www3.surrey.ac.uk/ces/files/pdf/0108_CES_WP_RELU_Integ_LCA_local_vs_global_vegs.pdf (accessed June 25, 2013).

10 Boriss, H. and Brunke, H. 2005. Lettuce Profile. Iowa State University. Available at Web site http://www.agmrc.org/commodities__products/vegetables/lettuce_profile.cfm. (verified February 27, 2012).

11 Hospido, A., Milà i Canals, L., McLaren, S., Truninger, M., Edwards-Jones, G., and Clift, R. 2009. The role of seasonality in lettuce consumption: A case study of environmental and social aspects. The International Journal of Life Cycle Assessment 14(5):381–391.

12 Coleman, E. and Damrosch, B. 1999. Four-Season Harvest: Organic Vegetables from Your Home Garden All Year Long. Chelsea Green, White River Junction, VT.

13 Carey, E., Jett, L., Lamont, W. Jr, Nennich, T., Orzolek, M., and Williams, K. 2009. Horticultural crop production in high tunnels in the United States: A snapshot. HortTechnology 19(1):37–43.

14 Stanhill, G. 1980. The energy cost of protected cropping: A comparison of six systems of tomato production. Journal of Agricultural Engineering Research 25(2): 145–154.

15 Van Hauwermeiren, A., Coene, H., Engelen, G., and Mathijs, E. 2007. Energy lifecycle inputs in food systems: A comparison of local versus mainstream cases. Journal of Environmental Policy and Planning 9(1):31–51.

16 Growers Supply. Available at Web site http://www.growerssupply.com/farm/supplies/prod1;gs_high_tunnels_cold_frames-gs_hightunnel_coldframe_acc;pg109842_109842.html (verified October 2010).

17 Smith, R., Cahn, M., Daugovish, O., Koike, S., Natwick, E., Smith, H., Subbarao, K., Takele, E., and Turini, T. Leaf Lettuce Production in California. University of California Agriculture and Natural Resources. Available at Web site http://ucanr.org/freepubs/docs/7216.pdf (accessed June 25, 2013).

18 Takele, E., Aguiar, J., and Walton, D. 1996. Production Practices and Sample Costs to Produce Loose Leaf Lettuce: Coachella Valley, Riverside County. University of California Cooperative Extension, USA.

19 Field Pack Commodities- Green Leaf. 2011. Church Brothers Produce. Available at Web site http://church

brothers.com/content/?page_id=114. (verified 21 March 2012).
20 SimaPro Database Manual Methods Library. 2006. PRé Consultants BV: Amersfoort, NL.
21 Goedkoop, M. and Spriensma, R. 2001. The Eco-indicator 99: A damage oriented method for Life Cycle Impact Assessment, Methodology Report. 2001. PRé Consultants BV: Amersfoort, NL.
22 Coley, D., Howard, M., and Winter, M. 2009. Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. Food Policy 34(2):150–155.

Renewable Agriculture and Food Systems: 29(4); 319–333 doi:10.1017/S1742170513000185

Mental models of organic weed management: Comparison of New England US farmer and expert models

Randa Jabbour[1]*, Sarah Zwickle[2], Eric R. Gallandt[1], Katherine E. McPhee[1], Robyn S. Wilson[2] and Doug Doohan[3]

[1]Department of Plant, Soil and Environmental Sciences, University of Maine, Orono, ME 04469, USA.
[2]School of Environment and Natural Resources, The Ohio State University, Columbus, OH 43210, USA.
[3]Department of Horticulture and Crop Science, The Ohio State University, Wooster, OH 44691, USA.
*Corresponding author: randa.jabbour@maine.edu

Accepted 17 May 2013; First published online 27 June 2013 **Research Paper**

Abstract

Weeds are a major challenge for organic farmers, yet we know little about the factors influencing organic farmers' weed management decisions. We hypothesized that farmers and scientist 'experts' differ in fundamental areas of knowledge and perceptions regarding weeds and weed management. Moreover, these differences prevent effective communication, outreach programming and research prioritization. An expert mental model, constructed primarily from interviews with research scientists and extension professionals, revealed expert emphasis on knowledge of ecological weed management as crucial for successfully implementing such strategies. We interviewed 23 organic farmers in northern New England, yielding an aggregate farmer mental model to compare with the expert model. Farmers demonstrated knowledge of the major concepts discussed by experts, but differed in emphasis. Farmers placed less emphasis on ecological complexity than experts. One-third of farmers interviewed discussed the potential role of weeds as indicators of soil nutrient status, a concept of which experts were skeptical. Farmer beliefs about the weed seedbank highlighted potential misconceptions regarding seed persistence, with one-fourth of farmers focusing on the concept that seeds can live for an exceptionally long time in the soil, while experts focused on the concept of the seed half-life. Farmers emphasized the role of experience, both their own and that of other farmers, rather than knowledge derived from scientific research. Farmers considered yield and the cost of time and labor as equally at risk because of weeds, whereas experts predominantly discussed yield loss. During discussions of management, both farmers and experts most emphasized risks associated with cultivation and benefits associated with cover cropping. These results have prompted us, first, to develop new educational materials focused on weed seed longevity and management of the weed seedbank, and, second, to conduct regional focus groups with farmers who prioritize fertility management in their efforts to control weeds, especially manipulations of soil calcium and magnesium.

Key words: mental models, organic agriculture, farmer beliefs, weed risks, seedbank management, critical weed-free management

Introduction

Weed management is a major challenge for organic and transitioning farmers[1]. Such farmers typically rely on short-term, high-cost control tactics such as hand weeding and cultivation[2,3] which, respectively, are costly and of variable efficacy. Increased weed density generally occurs in both organic and transitioning systems[4,5]. To improve this situation, scientists have placed considerable effort on researching ecological weed management (EWM) strategies, but they know little about how organic farmers' perceptions and knowledge of such strategies inform implementation.

Incorporating the human dimension of agricultural management into biological research provides a valuable perspective on implementation of these practices, particularly given there is as much diversity in the human dimension of management as in the biophysical resources that farmers manage[6]. Three recent studies provide insight into organic farmer weed management practices and beliefs in the Midwestern USA and the UK[3,7,8]. In terms of practice, in both the USA and the UK at least three-fourths of organic farmers discussed mechanical weeding, most often cultivation. EWM strategies such as seeding rate and variety choice were mentioned less often, roughly by one-third of farmers[3,8].

© Cambridge University Press 2013

In terms of the beliefs that may be informing attitudes toward practices, organic farmers in Ohio were less likely to mention biological concepts such as seed dormancy than their conventional counterparts[7], yet such knowledge is likely a critical component of successfully implementing EWM strategies[9]. However, there are many ways to construct knowledge, and organic farmers rely on experiential learning, trial and error, and problem solving to develop and reinforce their knowledge, which may or may not conform to 'best practices'[10,11]. Farmer knowledge has also been described as unspoken knowledge-in-practice, in contrast to formal, explicit knowledge[12]. For example, UK farmers associated success in weed management with informal on-farm trials of strategies, and ascribed failures to either inexperience or lack of time and money[8]. Overall, adoption of EWM strategies lags behind the widespread use of cultivation. We aimed to learn how farmer knowledge and perception of management tradeoffs influences their decision to implement a given strategy on their farm.

In this study, we constructed 'mental models' of New England organic farmers to summarize their knowledge, beliefs and perceptions of weeds and weed management[13]. A mental model can be described as a complex network of beliefs that affects how a person defines a problem, assesses risks and benefits, gathers and processes information, and makes decisions[14]. The mental models approach is designed to tell us how and what organic farmers think about weeds and weed management, and particularly how this compares to the scientists and extension professionals working to support them[7]. This approach has already been used to study perceptions and beliefs of conventional and organic farmers in Ohio regarding weed management, with a focus on herbicide resistance as the hazard[7,14,15], as well as with other agricultural hazards, such as microbial contamination on produce[16].

Our study compared farmer mental models to a baseline expert model of critical organic weed management knowledge[9]. We assessed (1) knowledge and beliefs regarding EWM strategies; and perceptions regarding (2) the risks and benefits of weeds; and (3) the risks and benefits of organic weed management strategies. Differences between the farmer and expert models in each of these areas will highlight areas of opportunity for improving extension-based communication and design of scientific research for the benefit of organic farmers. Focusing on the most salient beliefs, as well as potential inaccurate beliefs, in communication efforts can be the best route to knowledge-based behavioral change[17].

Methods

Expert model development

Development of the expert model is described briefly below; details regarding this process and outcome are described in full by Zwickle[9]. Sixteen 'experts' (eight PhD-level scientists, four extension specialists chosen because of involvement with farmer education, and four experienced organic farmers) were interviewed by phone or as part of a focus group in the winter of 2010. The farmers were identified by extension personnel as farmers particularly experienced with weed management, and they participated in focus groups to strengthen the expert model as a whole. This group represented three regions in the USA (the Northeast, Midwest and California) and one scientist from the Netherlands. Interviews began with open-ended questions about weeds, weed management and organic farmers. Once the expert exhausted his or her knowledge in response to an open-ended question, the interviewer used prompts to elicit more specific thoughts. Finally, the interview concluded with pointed questions ranging from beliefs about weeds to farmer experiences, risk perceptions and values.

The results of the expert interviews were organized into a conceptual model of the weed management decision-making process (Fig. 1). This model synthesized the expert view with decision science theories that recognize the tandem roles of experiential and deliberative processing in decision making[18–20]. First, experts believed that farm attributes, such as scale, and farmer attributes, such as knowledge, informed a farmer's perceptions of weeds and weed management. These beliefs are consistent with research that identifies how intuitive judgments of risk associated with a hazard (in this case weeds) vary by a range of individual characteristics[21]. In turn, these perceptions influenced the acceptability of management strategies, categorized here as either critical weed-free period (i.e., short-term, cultivation-based) or seedbank (i.e., longer-term, multi-tactic) strategies, consistent with research that identifies perceived risks and benefits as predictive of the acceptability of new technologies to users[22,23].

Farmer interviews

The concepts highlighted in the expert model were used to develop the farmer interview protocol available online (see Supplemental Table 1). Farmers were contacted by email based on recommendations from Maine Organic Farmers and Gardeners Association and Northeast Organic Farming Association. Participating farmers included those who responded affirmatively to the initial email solicitation and several who learned about the project in newsletter postings. Farmers from Maine ($n=12$), New Hampshire ($n=5$) and Vermont ($n=6$) were interviewed in fall 2010 by the same interviewer, using a consistent protocol.

We used a semi-structured open-ended interview strategy such that all farmers received the same initial prompts, but farmers were asked to clarify or provide more information about the concepts important to them. Interviews were conducted to uncover farmer knowledge,

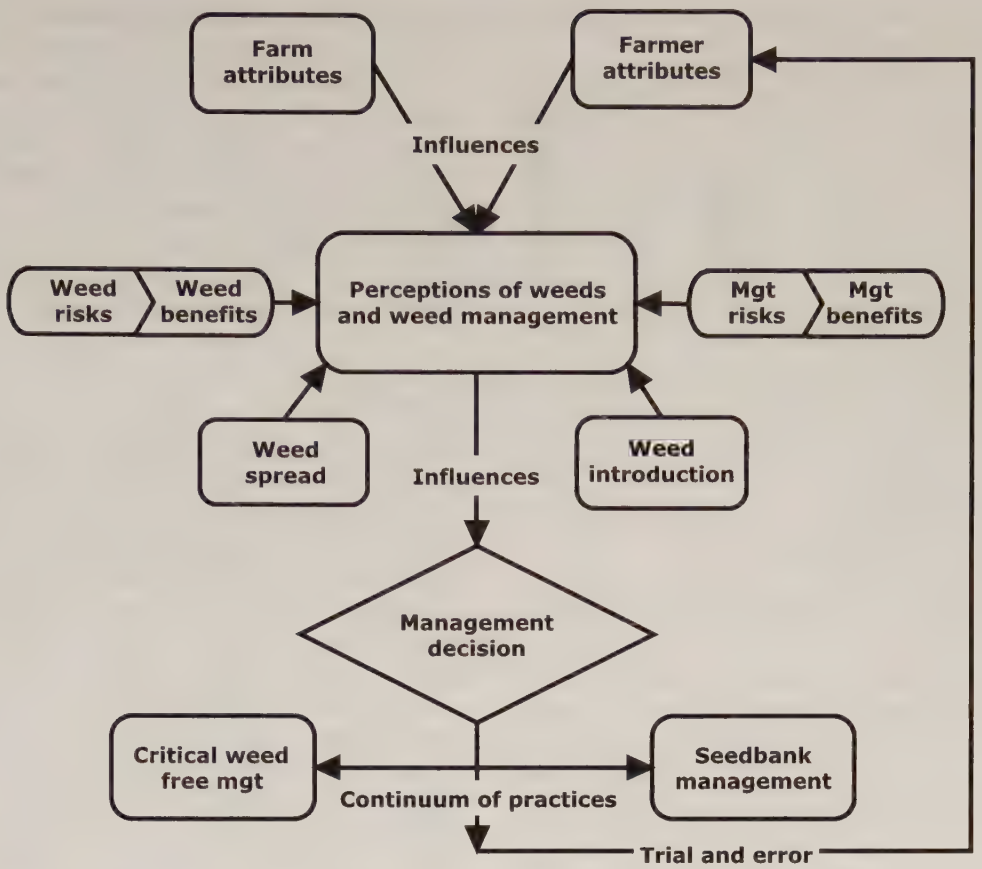


Figure 1. Conceptual model representing the expert view of the organic weed management decision-making process.

perceptions and experiences in a way that minimized the influence of the interviewer and provided farmers freedom of expression. At the same time, responses to questions were prompted in a focused way. For example, an interviewee may have responded to the open-ended question 'What is a weed?' with a narrative of undirected information. Further into the interview, however, the interviewer directed these responses to major areas identified by the expert model, for example 'what are the benefits of weeds?' A set of standard response phrases was prepared in advance to clarify answers without questioning their legitimacy, such as 'How did you come to that conclusion?'

The farmer interview protocol also included an exercise that required farmers to rank by ordering index cards with text that described various sources of information specific to the organic weed management decision-making process. The 16 options (Table 1) included sources of analytical information (e.g., latest science and research), experientially based information (e.g., what worked in the past) and value-based information (e.g., soil health). Farmers were asked to work quickly and rank them from most to least important in their decision-making process. This exercise was included to cross-validate the interview data and verify the importance of different types of information during the weed management decision-making process.

Interview coding

The interviews were independently transcribed and entered into the qualitative software program MAXQDA[24]. Coding has been defined as 'the analytic process through which concepts are identified'[25], through which labels are assigned to segments of the interviews, identifying what that segment was about. Each interview was coded separately according to the schematic developed from the expert model. If a farmer mentioned a concept not found in the expert coding schematic, it was added and marked as a uniquely farmer response. After the coding schematic was developed, it was tested for inter-coder reliability to examine its potential to produce repeatable results and to judge the intuitive logic of the model. Mental models studies expect coders to agree at least two-thirds[13]. Six farmer interviews were coded by an independent researcher, and inter-coder reliability tests revealed between 90 and 96% agreement in each interview.

Coding the frequency of response is important in mental models[13]. The more often a farmer mentioned a concept, the greater the importance in their decision-making process. If a farmer took time to explain a concept more fully, it was coded as only one mention, but the details of his or her responses within that concept were coded in detail. If a farmer mentioned the same concept later on, it was coded again. Coding hierarchically to

Table 1. Importance of 16 factors for weed management decisions, as ranked by farmers.

Factor	Overall rank
Type and timing of weed	1
What worked in the past	2
Time and labor	3
Crop yield	4
Immediate weed control	5
Soil health and structure	6
Environmental and ecological health	7
Respected farmer's advice	8
What farmers with similar soils or crops do	9
Family and worker health	10
Cash flow	11
Extension recommendations	12
Latest research and science	13
Markets and consumer demand	14
National Organic Program standards	15
Public perception	16

increasing level of detail provides a way to more accurately compare between groups (farmer to expert) and within groups (amongst farmers)[25–27]. For example, both experts and farmers agreed that agricultural causes of weed introduction are most important (86 and 69% weed introduction codes, respectively). However, at the next level of detail we observed that experts thought manure was the most important agricultural source of weeds (35% agricultural weed introduction codes) in contrast to farmers, who placed near equal emphasis on management behavior and manure (22 and 21% agricultural weed introduction codes, respectively).

Coding for knowledge

The expert model established long-term, ecologically based methods as crucial for reducing the risks associated with weeds on organic farms. Rather than asking a farmer directly about the general aspects of EWM, responses were coded when one of the principles was inherent in a farmer response to measure 'knowledge.' For example, Farmer 9 discussed the importance of rotating row crops with forage crops to utilize grazing as a way to reduce weed seed density. This discussion was coded in the knowledge area 'Managing Weed Seedbank,' in the particular concept 'Interrupting Weed Cycles Through Strategic Rotation.' Specifically, Farmer 9 said:

> "With forage—with the cows grazing it, they're eating up the seeds before they even become viable. If I can mix a forage rotation in there I can really reduce the amount of weed seeds for the next year."

Coding for management strategies

Management strategies were grouped according to whether they primarily allowed for a critical weed-free crop period (generally mechanical strategies targeting seedlings) or managed the seedbank[28]. The following strategies were grouped as critical weed-free period strategies: cultivation and tillage, hand weeding, organic herbicides, flaming, mowing and grazing. Seedbank management strategies included crop rotation, cover crops, mulch, nutrient management and seeding rates. For each strategy, codes were placed in the categories of location, timing, implementation and type, as appropriate, to capture detailed information of the specific context in which these strategies were discussed.

Data analysis

Results are reported as the percentage of codes within a category to compare the relative emphasis between farmers and experts. For instance, science and research comprised 58% of learning codes in the expert model in contrast to 9% of learning codes in the farmer model. To test for significant differences between farmer and expert emphasis, we calculated the difference between proportion of farmer mentions and proportion of expert mentions of a given concept. We used the Wilcoxon Signed Rank test to determine if the difference between farmers and experts significantly differed from zero. *P*-values <0.05 indicate divergence in emphasis between farmers and experts. For the farmer model, the number of farmers discussing a given concept (out of 23 total) is also reported. Finally, quotes are included to provide examples and context. Farmers are cited with their identification number with F19 indicating Farmer 19, for example.

Results and Discussion

This northeast New England farmer model was based on interviews with farmers who identified their major crops as either vegetables ($n=19$) or field crops ($n=4$). All field crop farmers interviewed were also dairy farmers. Gross farm income varied widely between these farms: 30% of farms ($n=7$) had a gross income of less than US$100,000; 35% of farms ($n=8$) had income in the US$100,000–250,000 range; 17% of farms ($n=4$) had income in the US$250,000–499,000 range; and 17% of farms ($n=4$, 2 dairy and 2 vegetable farms) had gross income greater than US$500,000. One farmer was new to organic farming (0–4 years of experience). Six farmers (26%) had 5–9 years of experience, eight farmers (35%) 10–14 years, and eight farmers (35%) more than 15 years.

The results that follow compare the farmer and expert models, with a focus on the role of (1) knowledge, (2) perceptions of weeds, and (3) perceptions of weed management strategies. We discuss particular farm attributes as they relate to perceptions, for example the importance of resources. We acknowledge the importance of farmer traits and values in decision making[9]; however, we will not focus on these topics here. In the final results

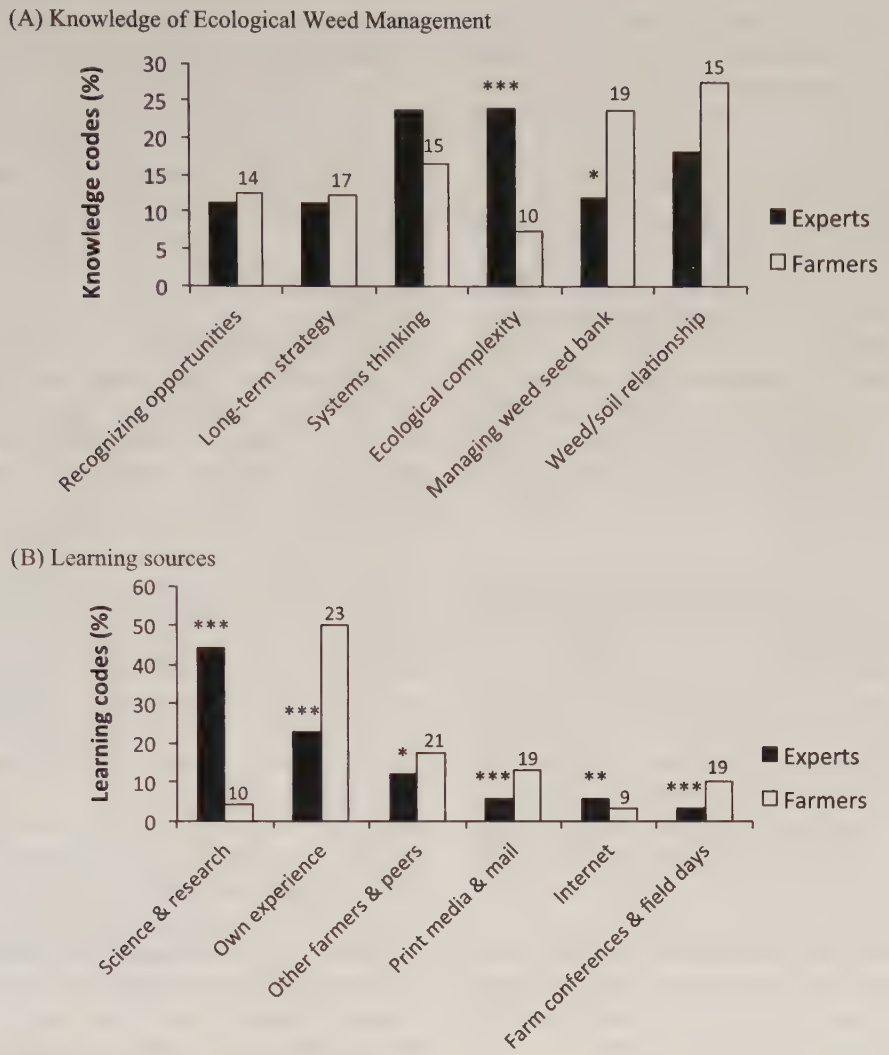


Figure 2. Relative emphasis on EWM knowledge concepts (A) and learning sources (B), according to frequency of codes in expert and farmer interviews. The number of farmers, out of 23 total, that discussed each concept is listed above the farmer bars. Bars labeled with *, ** or *** denote significant differences between expert and farmer emphasis at levels of $P<0.05$, 0.01 or 0.001, respectively.

section (Ranking exercise), we report results of the farmer ranking exercise.

Knowledge, learning and experience

Experts addressed knowledge of EWM according to six main topics (Fig. 2A). Farmers exhibited knowledge of each topic, although overall emphasis varied in comparison to experts (Fig. 2A). We report details of farmer and expert models below for each knowledge topic, followed by discussion of farmer seedbank beliefs and on-farm weeds. Finally, we address learning and the role of experience.

Ecological complexity. Experts placed more emphasis on ecological complexity than farmers ($P<0.001$, Fig. 2A). Experts repeatedly stated that organic farmers must be comfortable with and motivated by the complexity of organic systems in contrast to conventionally managed systems. Farmers did not dwell on complexity and were just as likely to identify conflict between their organic farming practices and ecological complexity, e.g., 'what's best for the ecosystem is if we just leave it the hell alone' (F10). Experts' discussion included connections between management and ecology (64% of ecological complexity codes)—specifically between marketing, labor and crop sequences; between suites of organisms; and the complex, undetermined cause and effect relationships regarding EWM. Experts believed that farmers want proof of a relationship between a given tactic and the success of weed management, but delayed results often make this difficult. Farmers also discussed connections between management and ecology, but focused on their dependency on weather or climate to achieve successful management (32% of farmer ecological complexity codes), a concept rarely mentioned by experts (3% of expert ecological complexity codes).

Systems thinking. Farmers and experts placed similar emphasis on systems thinking (Fig. 2A), with a focus on

the concept of diversifying. Experts discussed the role of crop diversity and crop rotations in EWM. An effective crop rotation for weed management included rotating cash crops with cover crops, and the timing of disturbances, not merely the crop sequence. Experts acknowledged the importance of crop rotation not only to maximize weed control, but also to contribute to the farm's fertility needs. Farmers' discussion of diversity (nine farmers) differed subtly from experts. In addition to specific details regarding their rotations, farmers described diversity of disturbances in their rotations, including tillage, fallows, mowing hay fields and grazing pasture. Farmers stated they use many strategies within the year, specifically citing the 'many little hammers' theory[29] or describing management practices as '...the tools in our toolbox...the weapons in my weapon chest' (F4).

Managing the weed seedbank. Farmers placed more emphasis on managing the weed seedbank than experts ($P=0.033$, Fig. 2A). Within this topic, experts and farmers both discussed the concept of interrupting weed cycles through rotation. Experts discussed stressing weeds at different points in their life cycle throughout the rotation and using strategically timed disturbances. They equally emphasized the importance of using appropriate tillage tactics, including minimizing use of tillage, and changing planting times. Farmers agreed that weed life cycles can be interrupted through crop rotation, and also emphasized using appropriate tillage tactics within a rotation (seven farmers). In contrast to experts, farmers placed more emphasis on pre-empting seed rain (nine farmers) than on changing planting times within a rotation (one farmer).

Relationships between weeds and soil. Farmers and experts placed similar emphasis on knowledge related to weed/soil relationships (Fig. 2A). Both groups discussed the concept that agricultural soils, due to high fertility, in particular nitrogen, invite weeds (nine farmers, 26% of farmer weed/soil codes and 24% of expert weed/soil codes). Farmers (12 farmers, 37% of weed/soil codes) and experts (8% of weed/soil codes) also discussed the relationship between weeds and soil structure, focused on the influence of compaction, drainage and soil texture. Farmers and experts showed divergence in their discussion of the relationship between weeds and soil nutrients. Experts expressed uncertainty regarding the relationship between weeds and nutrients other than nitrogen, specifically mentioning calcium, magnesium, and potassium[30] in their lengthy discussions on this topic (69% of expert weed/soil codes). One-third of farmers discussed associations between weeds and soil nutrients (19% of farmer weed/soil codes), ranging from general to explicit relationships between weed germination or presence and excess or deficient nutrients. Farmers uniquely discussed weeds as a way to 'heal' the soil (six farmers, 10% of farmer weed/soil codes) and weeds as 'indicators' (six farmers, 8% of farmer weed/soil codes) of problems with cultivation, nutrient levels and soil conditions such as compaction (Table 2). Farmers and experts diverged with beliefs of weeds as indicators for soil nutrients. Farmers discussed this concept in the same breath and with the same confidence and finality as the relationship between weeds and compaction or soil moisture, whereas experts were careful to distinguish between these concepts and weeds and nutrient balance. Experts varied in how dismissive they were of such claims (Table 2).

Long-term strategy. Experts and farmers both agreed on the importance of long-term strategy (Fig. 2A), focused on the concept of evidence-based management (ten farmers) and the challenge of proving effectiveness of long-term strategies. Farmers may need to wait several years before evidence of successful EWM implementation is apparent. In addition, seedbank management may require a short-term loss (e.g., land in summer fallow) to result in long-term gain (e.g., decreased seedbank). Farmer discussion of evidence-based management includes making decisions based on weed abundance in that year or the following year, a decision made on short-term gains (less observed weeds) that may discount longer-term goals such as soil health[31]. At the same time, farmers discuss the potential long-term benefits of soil quality as a result of cover cropping. This tension between long-term gain and short-term loss is apparent in both models.

Recognizing opportunities to manage weeds. Experts stressed the importance of a farmer's ability to recognize when, how and where to manage weeds. They identified concepts that enable farmers to recognize such opportunities: in particular, knowing the biology or type of the weed, timing management appropriately and knowing whether the weed is an annual or perennial. Farmers placed similar emphasis on knowledge of weed biology (nine farmers), explaining that in part their weed management decisions are in response to the type of weed or growth stage. They highlight the 'white thread' stage as an opportunity for management, and the importance of timing (five farmers).

Farmer seedbank beliefs. Each farmer was asked, 'How would you describe the term weed seedbank?' followed by 'How does it work on your farm?' Most coded responses regarding seedbank beliefs (71%) were in response to these questions, although farmers also discussed these beliefs throughout the interview (remaining 29% coded responses). Nearly half of these codes (47%, 22 farmers) were associated with a response describing the seedbank as 'viable seeds in the soil.'

Five farmers emphasized the maximum extent of seed longevity, mentioning seeds that can live from 20 to 80 years in the soil (8% seedbank belief codes). Farmers also stated that seed survival varies with soil depth (eight farmers, 8% seedbank belief codes). These farmers discussed the role of tillage and burial in determining depth of seeds in the soil profile, and consequently, whether these seeds would germinate or be susceptible to

Table 2. Weeds as indicators of soil conditions: divergent philosophies from expert and farmer models.

Experts	Farmers
Balanced soil	
'If you've got weeds on your farm, I know that a lot of growers see them as a farm out of balance or something, and if you just get the farm into balance then the weeds will disappear and I don't think that's true.' E1	'[Scientists are] just reductionist. Seed comes in, let it go to seed. You build up your population and you've got a weed problem, but I believe that with proper crop rotations and attention to soil fertility you are not going to have these problems. By using really well balanced compost and paying attention to your mineral balances you will go a long ways to not having weeds. That's my belief. I haven't mastered it yet though. If you want to know what my—in a nutshell what my attitude towards weeds is, that's what it is. It seems to me that the fields that I have the most weeds in are the ones that I have not taken care of as well as some of the other ones. The ones that I have kind of maybe cheated a little on my rotation, and didn't leave it in hay crop for enough years or...' F12
'But whether there are certain weeds indicative of a certain balance of nutrients, and I know that's a common thought by some organic farmers, I'm not sure there's really the research base to support it, not to say that there might not be some truth in that but I think we don't know enough to really support that.' E2	
'One of the characteristics of being an organic farmer is that you are trying to put your soil in balance in terms of nutrients and whether it's Acres USA style or some other style. It certainly makes sense to be considering the weeds in that process.' E3	
Weeds as indicators	
'You can talk with some degree of confidence about which weeds are very heavy nitrogen feeders, or what weeds do well in wetter or drier soil conditions, but I don't think there's a weed that tells you, oh, you know, I've got really high calcium. The calcium-magnesium ratio was this kind of a magical thing that farmers were talking about for a long time, and I don't see that has much merit actually.' E4	'Well it is definitely soil related. We have a couple of fields that are completely milkweed free, and it's not because there's no seed there. It's some soil reason that the milkweed germination is inhibited or something. I don't really know why.' F21
	'Sometimes weeds can give you an indication of correction that you need in your soil. For that matter, we always know that hempnettle is in fields where the fertility needs to be built. Lambsquarter, when you get that, it is testimony that you've got the fertility up and that becomes a bigger weed...Canadian thistle you've got compact ground.' F7

predation or decay. Expert discussion of seed longevity clarified that 'although some seeds are long-lived...the majority of weed seeds do not have a long life in soil.' In this context, experts explained that management practices such as zero-seed rain can have a measurable impact on weed densities over a short-time frame[4].

Weeds on their farms. Farmers were asked to name or describe the types of weeds on their farm, and identify the most and least problematic and risky weeds (Table 3). On average, farmers named nine species during the course of their interview, with a range of 5 to 13 species of weeds mentioned per farmer. Farmers most often mentioned hairy galinsoga (*Galinsoga ciliata*) as the most problematic and risky weed on their farms. They described hairy galinsoga as risky due to biological traits such as the short time before seed set and before germination. Farmers also considered it risky based on the experience of others: 'Other farmers say do whatever you can to keep that one out of your fields. I will go out of my way to pull that out...' (F4). Weed species discussed differed between vegetable and field crop farmers. Although hairy galinsoga was mentioned by roughly three-fourths of vegetable farmers, no field crop farmers mentioned this species. In turn, only field crop farmers mentioned thistle (*Cirsium* spp.). Common lambsquarters (*Chenopodium album*) was the weed species mentioned most often overall, but this species was most likely to be identified as the least risky and the least problematic weed. Farmers acknowledge that common lambsquarters produces a lot of seed, but describe it as being easy to identify, cultivate, pull by hand and control.

Learning and the role of experience. Experts most often discussed science and research-related sources for weed management knowledge, placing greater emphasis on this learning source than farmers (Fig. 2B, $P<0.001$). Farmers placed more emphasis on learning from their own experience (Fig. 2B, $P<0.001$). Farmers discussed knowledge gained from trial and error, specifically regarding timing (ten farmers), weed life cycles (nine farmers), crop rotation (eight farmers), equipment (six farmers) and soil fertility (five farmers). Farmers placed more emphasis on learning from other farmers ($P=0.014$), print media ($P=0.001$), and farm conferences and field days ($P<0.001$) than experts. Experts placed more emphasis on learning from the internet than farmers, although this was a small category in both farmer and expert models ($P=0.004$).

Perceptions of weeds, weed introduction and spread

Risks of weeds. Farmers were specifically asked whether there are risks and benefits to having weeds on the farm. Both experts and farmers mentioned the risks of weeds more than twice as often as the benefits of weeds. Risks of weeds were coded in four major categories: agricultural,

Table 3. Weeds mentioned during farmer interviews.

Weed species	Common name	Mentions[3]	Number of farmers[1] (vegetable, field crop)	Problematic[2]		Risky[2]	
				Most	Least	Most	Least
Chenopodium album	Common lambsquarters	47	(16, 3)	3	8	1	8
Amaranthus retroflexus	Redroot pigweed	45	(16, 3)	2	7	1	6
Galinsoga ciliata	Hairy galinsoga	42	(14, 0)	7	0	11	0
Elytrigia repens	Quackgrass	33	(9, 3)	2	1	5	2
Digitaria spp.	Crabgrasses	27	(11, 0)	5	0	1	0
Poaceae spp.	Grasses	17	(8, 1)	4	0	4	0
Stellaria media	Chickweed	17	(6, 0)	2	1	2	3
Portulaca oleracea	Purslane	15	(9, 0)	1	3	1	2
Cyperus esculentus	Yellow nutsedge	12	(5, 1)	1	0	0	0
Brassica spp.	Mustards	11	(5, 2)	2	2	1	1
Capsella bursa-pastoris	Shepherd's purse	10	(7, 0)	1	1	0	2
Ambrosia artemisiifolia	Common ragweed	9	(6, 1)	1	1	1	1
Asclepias syriaca	Common milkweed	8	(1, 1)	1	0	0	0
Arctium minus	Common burdock	6	(1, 2)	0	0	0	0
Cirsium spp.	Thistle	6	(0, 2)	0	1	1	1

[1] Number of farmers in each farm type (from a total of 19 vegetable and four field crop farmers) that mentioned a given weed.
[2] Number of farmers that identified a weed as most or least problematic or risky.
[3] Total number of mentions summed over all farmer interviews.

economic, ecological and social. Farmers and experts both discussed agricultural and economic risks of weeds most often (Table 4). Both farmers and experts agreed on the agricultural risk of competition by weeds (70 and 54% of farmer and expert agricultural risk codes, respectively; $P=0.157$; 19 farmers). Farmers discussed the rapid growth of weeds and their ability to compete for nutrients, moisture and sunlight, concepts included in the expert model. Experts, and farmers to a lesser extent ($P=0.018$), identified a weed's ability to exploit niches as risky (25 and 12% of expert and farmer agricultural risk codes, 14 farmers). Economic risks closely followed agricultural risks in importance to both farmers and experts, in particular risks associated with production. Experts emphasized risk of reduced yield more than farmers ($P<0.001$, 71% expert versus 39% farmer production risks, 18 farmers), whereas farmers placed more emphasis on the risk of time and labor costs due to weeds than experts ($P=0.006$; 27% farmer versus 9% expert production risks, 15 farmers). As described by farmer 5,

> "Labor is one of our biggest concerns. The margin of profit of any of these things is so slim that if you put too much labor into trying to weed them, then you're not making any money on it."

Benefits of weeds. Farmers discussed agricultural benefits of weeds more often than experts, who, in turn, discussed ecological benefits of weeds more often than farmers (Table 4). However, both groups discussed ecological and agricultural benefits more than economic and social benefits of weeds, which they agreed were minimal (Table 4). Farmers and experts agreed that the primary agricultural benefit provided by weeds is for the soil ($P=0.441$; 88 and 89% of agricultural benefits, respectively). Farmers primarily described this as weeds 'acting like a cover crop' (31% of codes in soils category, 18 farmers), an analogy experts used less often (8% of soils codes in expert model). Experts focused on the concept of weeds adding organic matter and nutrients to the soil (28% codes), a concept also mentioned by farmers (11% codes). Farmers and experts also discussed the contribution of weeds to nutrient cycling of soils (15 and 12% codes, respectively) and erosion prevention (19 and 20% of codes in soils category, respectively).

Experts placed more emphasis on the ecological benefits of weeds as habitat ($P=0.035$) and as biodiversity ($P<0.001$) than farmers. Experts and farmers agreed on the beneficial role weeds play as part of the agroecosystem ($P=0.115$) and as food for wildlife ($P=0.858$). Farmers uniquely described weeds as Mother Nature's way of healing the soil, for instance by colonizing disturbed ground. The beneficial ecological role of weeds has become a popular research topic in the European Union, with recent studies emphasizing the role of weed species diversity[32,33] and the role of weeds in food webs[34,35].

Perceptions of weed introduction. Both farmers and experts discussed weed introduction due to agricultural causes most often, although experts placed relatively more emphasis on agricultural sources of introduction than farmers (Table 4). Farmers placed more emphasis on wildlife as sources of weed introduction (Table 4). Experts placed more emphasis on manure and compost as agricultural sources of weed introduction than farmers, whereas farmers placed more emphasis on farmer behavior (Table 5). Experts may be overemphasizing the role of manure that generally contributes a small number of seeds

Table 4. Perceptions of weeds according to experts and farmers. Percentages reported reflect the relative emphasis based on frequency of codes from interviews.

	Expert (%)	Farmer (%)	Farmers (number)[1]	*P*-value[2]
Risks of weeds				
Agricultural	56	40	23	0.001
Economic	30	36	23	0.157
Ecological	9	5	9	0.564
Social	3	19	22	0.001
Benefits of weeds				
Agricultural	43	59	22	0.011
Economic	3	3	4	0.090
Ecological	48	31	18	0.009
Social	3	3	4	0.090
Philosophical	0	3	4	0.130
Weed introduction				
Agricultural	86	69	22	0.005
Natural occurrences	5	11	11	0.062
Wildlife	0	12	10	0.002
Social	9	8	5	0.297
Weed spread				
Agricultural	66	64	19	0.863
Natural occurrences	10	14	10	0.689
Wildlife	11	9	5	0.375
Social	0	5	1	1.000
Biological	14	9	6	0.001

[1] Number of farmers (out of 23 total) that discuss a particular perception category.
[2] Wilcoxon sign-rank test for difference in emphasis between experts and farmers.

relative to the existing seedbank[36]. Unique introduction of pernicious species is, however, a legitimate concern. Farmer discussion of behavior included the role of previous cropping systems, such that weeds were brought in historically or already on the farm (six farmers). Farmers and experts placed similar emphasis on natural and social occurrences as sources of weed introduction (Table 4).

Perceptions of weed spread. Farmers and experts agreed on agricultural causes as the dominant source of weed spread (Table 4), specifically farmer behavior as the most important factor (Table 5). Expert discussion of farmer behavior focused almost entirely on allowing weeds to set seed. Farmers discussed allowing weeds to set seed (seven farmers) as well as seeds spread by foot travel (seven farmers). Farmers placed more emphasis on mechanical causes of weed spread than experts (Table 5), primarily discussing movement with equipment. Experts placed more emphasis on biological causes of weed spread than farmers, but overall discussed this concept much less often than agricultural causes (Table 4). The farmers interviewed were very management centered, and they took a great deal of responsibility for weed introduction and spread, more so than conventional farmers interviewed in the Midwest[14] who placed more emphasis on factors such as flooding that were out of their control.

Table 5. Agricultural causes of weed spread and introduction. Percentages reported represent the relative emphasis based on frequency of codes from interviews by experts and farmers.

	Expert (%)	Farmer (%)	Farmers (number)[1]	*P*-value[2]
Weed introduction				
Raw manure	35	21	13	0.004
Compost	25	14	6	0.008
Farmer management behavior	10	22	11	0.040
Seed sources	8	14	7	0.830
Weed spread				
Farmer management behavior	39	36	15	0.940
Mechanical	24	40	15	0.015
Seedbank	17	4	2	0.001

[1] Number of farmers (out of 23 total) that discuss a particular category.
[2] Wilcoxon sign-rank test for difference in emphasis between experts and farmers.

Weed management perceptions

We first discuss practices associated with critical weed-free management (e.g., cultivation and tillage, hand weeding and flaming), followed by seedbank management (e.g., cover cropping and green manures, crop rotation and mulches). We view these approaches to weed management as reflective of seedling-focused, short-term, reactionary practices, in contrast to longer-term, more system-level practices. We recognize that individual farmers may be successful by emphasizing either philosophy, and that most employ a combination of management practices that are seedling- as well as system-focused.

Risks and benefits were categorized as agricultural, economic, ecological or social (Table 6). Farmers and experts both placed more emphasis on benefits of seedbank management practices than on benefits of critical weed-free management practices ($P=0.463$), mentioning benefits of seedbank management practices 1.6–1.8 times more often. The most discussed type of seedbank management benefits, agricultural, were equally emphasized by farmers and experts ($P=0.224$). Farmers placed more emphasis on agricultural benefits of critical weed-free management than experts (Table 6, $P=0.005$). Experts uniquely discussed ecological benefits to critical weed-free strategies, although this was less important than agricultural and economic benefits.

Farmer discussion of risks was more focused on critical weed-free practices than expert discussion ($P=0.032$). Farmers discussed risks of critical weed-free practices 4 times as often as risks of seedbank management practices, in contrast to expert discussion 2.3 times as often. However, the relative emphasis on types of risk was similar between farmers and experts (Table 6, $P>0.1$ for all categories). Farmers and experts most often discussed agricultural risks, followed by economic risks.

Table 6. Risks and benefits of weed management strategies. Percentages reported represent the relative emphasis based on frequency of codes from interviews by experts and farmers.

	Critical weed-free period management[1]		Seedbank management[2]	
	Expert (%)	Farmer (%)	Expert (%)	Farmer (%)
Risks				
Agricultural	52	58	70	60
Economic	27	26	24	21
Ecological	19	14	6	18
Social	2	3	0	1
Benefits				
Agricultural	37	65	55	65
Economic	45	30	11	16
Ecological	11	0	26	19
Social	8	5	8	0

[1] Strategies that allowed for critical weed-free period, generally mechanical strategies targeting seedlings.
[2] Strategies that managed the seedbank.

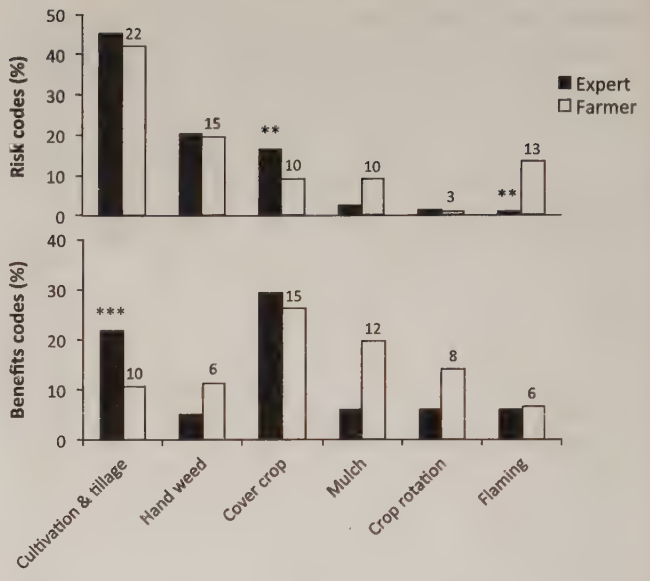


Figure 3. Relative emphasis on risks and benefits of weed management practices, according to frequency of codes in expert and farmer interviews. The number of farmers, out of 23 total, that discussed each concept is listed above the farmer bars. Bars labeled with ** or *** denote significant differences between expert and farmer emphasis at levels of $P<0.01$ or 0.001, respectively.

In the following sections, we present results and discussion for the six types of management practices most discussed by farmers. Farmers and experts also discussed other practices less frequently, including mowing, grazing, herbicides, nutrient management, crop choice and seeding, tiling and use of transplants. The relative emphasis reported in Fig. 3 was calculated based on all discussed practices.

Cultivation and tillage. Farmers and experts most often discussed bare fallow or stale seedbed cultivation practices (16 farmers), including the importance of completing multiple passes with equipment. Both groups discussed the importance of timing cultivation when weeds are small (six farmers), specifically mentioning the 'white thread stage' during which seedlings are most susceptible to cultivation (seven farmers).

Experts and farmers agreed that cultivation and tillage was the riskiest practice overall ($P=0.459$). They primarily discussed agricultural risks of cultivation and tillage such as missing cultivation windows (19 farmers), particularly in 'too wet' conditions. Both groups acknowledged risks of implementation associated with crop damage (eight farmers) and ecological risks of damage to soils and erosion (nine farmers). Farmers uniquely discussed economic risks of cultivation: cost of time, labor, purchasing and using a tractor (five farmers). Experts placed more emphasis on the benefits of cultivation and tillage than farmers ($P<0.001$). Experts primarily discussed economic benefits, including the concept that controlling weeds through cultivation pays for itself through increased crop yield, and that accepting some crop damage can result in better yield due to decreased competition. Farmers did not discuss the latter concept.

Hand weeding and hoeing. Farmers discussed both hoeing (13 farmers) and hand pulling (eight farmers). They emphasized timing, particularly two main concepts: (1) hand weeding before a weed goes to seed to preempt seed rain, and (2) hoeing at the white thread stage. Experts did not focus on timing, and discussed instead whether the entire plant, roots included, needed to be removed depending on the species, as well as use of the correct tool. Hand weeding was the second riskiest practice discussed by both experts and farmers ($P=0.657$, Fig. 3). Experts placed nearly all emphasis on economic risks of hand weeding, whereas farmers also acknowledged other types of risks. Economic risks focused on the cost and availability of time and labor associated with hand weeding (12 farmers). Social risks discussed by farmers focused on the challenging nature of hand weeding. Experts and farmers both discussed benefits of hand weeding minimally ($P=0.492$, Fig. 3).

Flaming. Experts and farmers discussed flaming both pre- and post-emergence, and implementing it as a stale seedbed strategy. Farmers exhibited more concern of risks associated with flaming than experts ($P=0.008$, Fig. 3) mentioning danger, panic and setting a field on fire (12 farmers). Timing of flaming was identified as crucial (five farmers), 'critical within hours' (F13). Farmers and experts agreed on the emphasis on benefits of flaming ($P=0.470$), particularly the added flexibility flaming allows in response to weather conditions when preparing a seedbed. Farmers discussed the value of the stale seedbed approach of killing weed seedlings without also bringing up new seeds as you would with a cultivation-based, false seedbed technique[37].

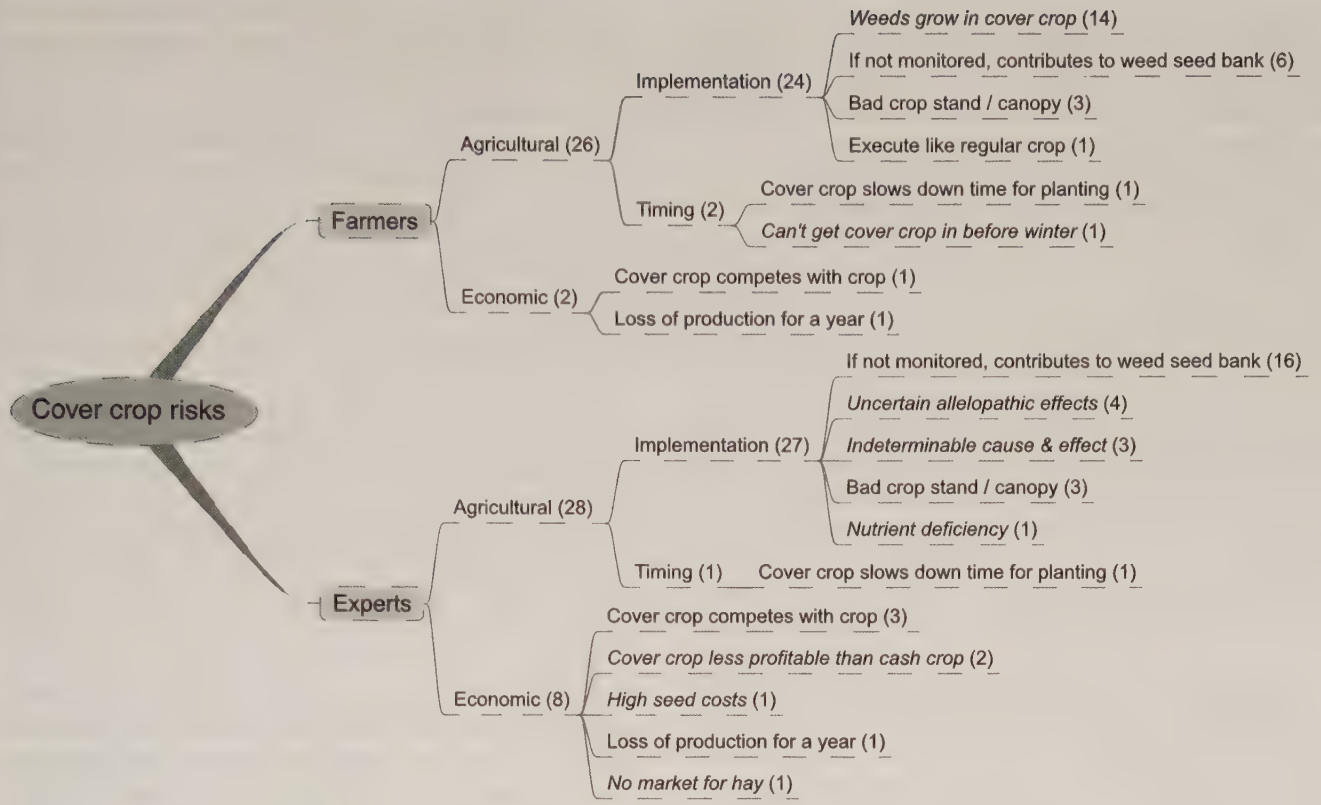

Cover crop risks
Farmers
Agricultural (26)
Implementation (24)
Weeds grow in cover crop (14)
If not monitored, contributes to weed seed bank (6)
Bad crop stand / canopy (3)
Execute like regular crop (1)
Timing (2)
Cover crop slows down time for planting (1)
Can't get cover crop in before winter (1)
Economic (2)
Cover crop competes with crop (1)
Loss of production for a year (1)
Experts
Agricultural (28)
Implementation (27)
If not monitored, contributes to weed seed bank (16)
Uncertain allelopathic effects (4)
Indeterminable cause & effect (3)
Bad crop stand / canopy (3)
Nutrient deficiency (1)
Timing (1)
Cover crop slows down time for planting (1)
Economic (8)
Cover crop competes with crop (3)
Cover crop less profitable than cash crop (2)
High seed costs (1)
Loss of production for a year (1)
No market for hay (1)

Figure 4. Detailed categorical breakdown of cover cropping risks cited by farmers and experts. Numbers in parentheses indicate number of codes in each category. Unique concepts, mentioned only by farmers or experts, but not both groups, are indicated by italic font.

Crop rotation. Farmers were asked, 'Do you use crop rotation to manage weeds? If so, what makes a crop rotation successful at managing weeds?' Twenty-one farmers said they used crop rotation to manage weeds, although several qualified that weeds are considered in combination with disease, fertility requirements and soils. Farmers discussed rotating crops that are easier to control weeds in or 'keep clean' with those that are not (ten farmers). Six farmers described using rotation to temporally break weed life cycles.

Farmers and experts rarely discussed risks from crop rotation (Fig. 3). Experts indicated that vegetable growers may not execute a crop rotation in the same way a grain grower would, for example. Organic vegetable farmers often rely on particular sequences of crops, e.g., 'couplets,' but not longer-term, predictable sequences[38]. One vegetable farmer supported this claim, explaining that she 'can't have a specific crop rotation' due to variability in soil moisture on her farm. Farmers and experts placed similar emphasis on crop rotation benefits ($P=0.691$), discussing agriculture, economic and ecological benefits.

Cover cropping and green manures. Farmers were asked, 'Do you use cover crops to manage weeds? If so, what makes a cover crop successful at weed management?' Sixteen farmers stated that they use cover crops to manage weeds, using them as a physical barrier, as well as mowing the cover crop. Cover crop management details were coded as regarding implementation, timing or type. The expert model included roughly 3 times more implementation codes than timing codes; in contrast, the farmer model included 12 times more implementation codes than timing codes. In other words, farmers rarely discussed timing of cover crop management.

Farmers and experts offered a detailed assessment of both the risks and benefits of implementing cover crops. Overall, experts placed more emphasis on the risks of cover crops than farmers ($P=0.005$). Both groups discussed agricultural risks of implementing cover crops most often, particularly that weeds grow in cover crops and that both weeds and cover crops could contribute to the seedbank if not monitored and controlled (Fig. 4). Experts placed more emphasis on economic risks of cover crops than farmers. Farmers rarely mentioned these economic risks (Fig. 4), perhaps because they use cover crops for benefits beyond weed management.

Farmers and experts, in agreement ($P=0.532$), mentioned benefits of cover cropping most often among management strategies discussed (Fig. 3). Farmers most often mentioned benefits of cover crops to soils by adding organic matter, fertility and preventing erosion (nine farmers, 50% of cover crop benefits codes). Farmers also discussed the ability of a cover crop to smother, outcompete and shade weeds (seven farmers, 25% of cover

Table 7. Key communication points based on incongruities between farmer and expert weed management knowledge and perceptions.

Farmer beliefs	Communication/research recommendations
Most salient	
• Economic impact of weed management is multi-dimensional—more than simply yield loss	• Incorporate the cost of time and labor and crop quality along with reduced yield to better represent economic impact of weed management strategy for farmers
• Weed management decisions are closely aligned with soil quality	• Identify benefits or risks of weed management to soil quality. Conduct research testing cultivation effects on soil quality
• Farmers are management-centered rather than ecology-centered	• Focus on solutions to specific problems rather than generality of ecological complexity
• Farmers learn best from their own experience and that of other farmers	• Implement on-farm trials; engagement with farmer advisory boards throughout research process
Potential misconceptions	
• Weed seeds live in the soil for 20+ years	• Illustrate species-specific effects of weed management practices that target seedbank (e.g., zero seed rain); demonstrate practical implications of 'half-lives'
• Weeds are indicators of soil nutrients	• Distinguish between effects of nitrogen and nutrients such as calcium and magnesium on weeds. Conduct further research on base cation ratio on weeds

crop benefits). Experts placed more emphasis on benefits to soils (79% of cover crop benefits), and less emphasis on competition with weeds.

Mulches. Experts and vegetable farmers discussed both black plastic mulches (12 farmers) and organic mulches (ten farmers), such as straw, crop residue and landscape fabric. Experts and farmers placed similar emphasis on risks of mulch ($P=0.301$, Fig. 3), both groups discussing ecological risks of plastic mulch, focused on the waste associated with use of this practice (seven farmers), and economic risks, including the costs of mulch, time and labor. Farmers uniquely discussed risks of weed growth between pathways and rows, efficacy only against certain weeds and introducing weed seed in dirty straw mulch. Farmers and experts agreed on benefits of mulch ($P=0.064$), such as smothering weeds (four farmers) and warming up the soil faster (four farmers), important in the short New England growing season.

Ranking exercise

Farmers quickly ranked 16 factors in order of importance to them when making weed management decisions (Table 1). The most important factors were: (1) type and timing of weed; (2) what worked in the past; and (3) available time and labor. These priorities align with the results of the coded interviews, with farmers relying heavily on their own experience as a source of knowledge, and emphasizing the constraint of time and labor as a major risk of weeds.

Conclusions

This study was motivated by the goal of improving EWM outreach and research to better target organic farmers. New England farmers, as a group, demonstrated knowledge of the major concepts important to experts, although there were differences in emphasis between experts and farmers. Farmers were management-centered, more concerned with management of the weed seedbank than the ecological complexity that surrounds it. They discussed specifics rather than complex generalities, for instance focusing on specific problem species. Knowledge about weeds and available management strategies does not appear to be a general constraint for organic farmers as much as constraints of time and labor. However, there were gaps between expert and farmer beliefs regarding two components of weed biology, weeds as indicators of soil nutrient levels and weed seed longevity.

One-third of farmers discussed weeds as indicators of soil conditions. Experts usually discussed this concept with skepticism or uncertainty. The idea of a 'balanced' soil, with ideal base cation saturation ratios, is promoted by some private soil-testing laboratories and is discussed in several popular publications as an effective weed management practice[39,40]. The general argument is compelling: Weeds are simply indicators of soil problems; address the 'root of the problem' by correcting the soil problem and, by extension, weeds will no longer be a problem. Weed scientists have conducted considerable research on fertility effects on weeds, generally focusing on selective delivery of nitrogen to crop plants[41]. A recent review on this subject concludes that existing data do not support the base cation saturation ratio concept[42], and effects were not observed in the two published accounts of field studies[43,44].

Weed seed longevity is another belief to target in future communication efforts. One-fourth of farmers focused on the maximum length of time seeds live in the soil. Knowledge of seed longevity for different species can strongly influence management choices farmers make. For instance, the impact and timeliness of zero seed rain

practices or burying seed with inversion tillage will vary with the seed longevity of a given species. Hairy galinsoga, the species named as most problematic and most risky by New England vegetable farmers, lacks dormancy in the soil[45]. Data on actual seed decay indicates that farmers may be overestimating seed longevity in the soil[46]. In other words, farmers focus on the relatively low number of seeds that persist many years rather than the large decline in seed density in the first few years, when most seed loss occurs. Farmers do, however, discuss this in species-specific contexts, for instance always making sure to hand weed species such as mustard.

Scientific research was not of great importance to farmers when making weed management decisions (Table 1). Farmers placed a great deal of emphasis on learning from their own experiences and those of other farmers, consistent with other studies[8,10–12]. Scientists and extension professionals can work to incorporate these learning avenues into future research and outreach. Funding agencies such as the USDA now emphasize stakeholder involvement and participatory research as a necessary component of research projects. Examples of participatory learning of weed science has been demonstrated both in classroom and extension settings[47,48]. Mental models research findings should be used to decide both the content of outreach materials as well as the framing and delivery of these messages[13] to best address both misconceptions and farmers' most salient beliefs (Table 7). Our research suggests that scientists and extension professionals need to focus more on the framing of educational materials to address the farmer priorities of soil quality and time and labor. Collaboration among weed scientists, soil scientists and economists to produce outreach material could provide more realistic framing in contrast to traditional, discipline-specific materials.

A long-held basic tenant of organic agriculture, soil health is mentioned repeatedly amongst farmers. The major risks of cultivation and tillage discussed were damage to soils, and the major benefits of cover cropping were for soils. Farmers described scenarios in which they knew that their cover crop was detrimental due to weed management, but beneficial to soils, thus they let it grow. Weed management research that not only measures yield effects, but also includes a multi-dimensional assessment of time and labor constraints and effects on soil health, may better serve farmers. Tools such as spider plots used to assess ecosystem services of cover crops[47,49] could be modified to incorporate economic components and information regarding effects on specific problematic weed species in a given region[8].

All farmers interviewed discussed cultivation as a critical strategy and demonstrated awareness of the risks of this practice, in agreement with expert emphasis on cultivation risks. Adoption of seedbank management approaches such as crop rotation and use of cover crops were widespread among this population as well, although the motivation was not purely driven by weed problems. Cover crop perceptions in particular were exemplary of the depth of understanding the mental models approach provided, illustrating risk and benefit tradeoffs that farmers face, and the importance of context of the management practice—success or failure depending on the type of weed being managed, the type of cover crop, how it is implemented (seeding density, residue management) and timing. This goes far beyond asking organic farmers whether they use cover crops on their farm. Farmers and experts agreed that cover crops provide many benefits, yet farmers placed less relative emphasis on risks of cover cropping (Fig. 3). Education and outreach can capitalize on this by providing details on the types of benefits and risks of cover cropping, and the management strategies or context (type of crop or weed) that magnify or minimize either the benefits or risks. For example, several farmers clarified that it is the disturbance associated with cover crops that manages the seedbank rather than cover crops themselves, a point supported by recent research[50].

In conclusion, these incongruities have prompted us to develop new educational materials focused on weed seed longevity and management of the weed seedbank, and, secondly, to conduct regional focus group meetings with farmers who prioritize fertility management in their efforts to control weeds, especially manipulations of soil nutrients. More broadly, we will frame organic weed management outreach in the context of the soil health, economic and labor benefits whenever possible, to better relate to the whole-farm priorities of organic farmers. Future communication efforts should be evaluated to assess changes in beliefs or practices by farmers.

Acknowledgements. We are exceedingly grateful to the twenty-three Maine, New Hampshire and Vermont farmers who participated in these interviews. This research was supported by the United States Department of Agriculture, Organic Agriculture Research and Extension Initiative competitive grant program ('Mental Models and Participatory Research to Redesign Extension Programming for Organic Weed Management.' USDA Award No. 2009-51300-05653). The manuscript was improved thanks to thoughtful comments from two anonymous reviewers. This is Publication Number 3321 from the Maine Agriculture and Forestry Experiment Station.

Supplementary online material is available at http://cambridge.journals.org/RAF.

References

1 OFRF. 1998. Third Biennial National Organic Farmer's Survey. Organic Farming Research Foundation, Santa Cruz, CA.

2 Riemens, M.M., Groeneveld, R.M.W., Kropff, M.J.J., Lotz, L.P., Renes, R.J., Sukkel, W., and van der Weide, R.Y. 2010. Linking farmer weed management behavior with weed pressure: More than just technology. Weed Science 58:490- 496.

3 Dedecker, J. 2012. Weed management practice selection among Midwest U.S. organic growers. MS thesis, University of Illinois at Urbana-Champaign, Urbana, IL, p. 146.

4 Riemens, M.M., Groeneveld, R.M.W., Lotz, L.P., and Kropff, M.J. 2007. Effects of three management strategies on the seedbank, emergence and the need for hand weeding in an organic arable cropping system. Weed Research 47:442–451.
5 Hawes, C., Squire, G.R., Hallett, P.D., Watson, C.A., and Young, M. 2010. Arable plant communities as indicators of farming practice. Agriculture, Ecosystems and Environment 138:17–26.
6 Nowak, P.J. and Cabot, P.E. 2004. Human dimension of resource management programs. Journal of Soil and Water Conservation 59:128–135.
7 Doohan, D., Wilson, R., Canales, E., and Parker, J. 2010. Investigating the human dimension of weed management: New tools of the trade. Weed Science 58:503–510.
8 Turner, R.J., Davies, G., Moore, H., Grundy, A.C., and Mead, A. 2007. Organic weed management: A review of the current UK farmer perspective. Crop Protection 26:377–382.
9 Zwickle, S. 2011. Weeds and organic weed management: Investigating farmer decisions with a mental models approach. MS thesis, Ohio State University, Columbus, OH, p. 171.
10 Eckert, E. and Bell, A. 2005. Invisible force: Farmers' mental models and how they influence learning and actions. Journal of Extension [Online] 43. Available at Web site http://www.joe.org/joe/2005june/a2.php (accessed June 12, 2013).
11 Eckert, E. and Bell, A. 2006. Continuity and change: Themes of mental model development among small-scale farmers. Journal of Extension [Online] 44. Available at Web site http://www.joe.org/joe/2006february/a2p.shtml (accessed June 12, 2013).
12 Macé, K., Morlon, P., Munier-Jolain, N., and Quéré, L. 2007. Time scales as a factor in decision-making by French farmers on weed management in annual crops. Agricultural Systems 93:115–142.
13 Morgan, M.G., Fischhoff, B., Bostrom, A., and Atman, C.J. 2002. Risk Communication: A Mental Models Approach. Cambridge University Press, Cambridge, UK.
14 Wilson, R.S., Tucker, M.A., Hooker, N.H., LeJeune, J.T., and Doohan, D. 2008. Perceptions and beliefs about weed management: Perspectives of Ohio grain and produce farmers. Weed Technology 22:339–350.
15 Wilson, R.S., Hooker, N., Tucker, M., LeJeune, J., and Doohan, D. 2009. Targeting the farmer decision making process: A pathway to increased adoption of integrated weed management. Crop Protection 28:756–764.
16 Parker, J.S., Wilson, R.S., LeJeune, J.T., and Doohan, D. 2012. Including growers in the 'food safety' conversation: Enhancing the design and implementation of food safety programming based on farm and marketing needs of fresh fruit and vegetable producers. Agriculture and Human Values 29:303–319.
17 Ajzen, I. 1991. The theory of planned behavior. Organizational Behavior and Human Decision Processes 50:179–211.
18 Plous, S. 1993. The Psychology of Judgment and Decision Making. McGraw Hill, Columbus, OH.
19 Damasio, A. 1994. Descartes' Error: Emotion, Reason, and the Human Brain. Cambridge University Press, New York, NY.
20 Corselius, K.L., Simmons, S.R., and Flora, C.B. 2003. Farmer perspectives on cropping systems diversification in northwestern Minnesota. Agriculture and Human Values 20:371–383.
21 Sjöberg, L. 2000. Factors in risk perception. Risk Analysis 20:1–11.
22 Siegrist, M. 1999. A causal model explaining the perception and acceptance of gene technology. Journal of Applied Social Psychology 29:2093–2106.
23 Siegrist, M., Cvetkovich, G., and Roth, C. 2000. Salient value similarity, social trust, and risk/benefit perception. Risk Analysis 20:353–362.
24 MAXQDA, Software for Qualitative Data Analysis. 1989–2013. VERBI Software—Consult—Sozialforschung GmbH, Berlin, DE.
25 Corbin, J. and Strauss, A. 2008. Basics of Qualitative Research. Sage Publications, Los Angeles, CA.
26 Glesne, C. and Peshkin, A. 1992. Becoming Qualitative Researchers: An Introduction. Longman, White Plains, NY.
27 Charmaz, K. 2009. Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis. Sage Publications, Los Angeles, CA.
28 Gallandt, E.R. 2006. How can we target the weed seedbank? Weed Science 54:588–596.
29 Liebman, M. and Gallandt, E.R. 1997. Many little hammers: Ecological management of crop-weed interactions. In L.E. Jackson (ed.). Ecology in Agriculture. Academic Press, San Diego, CA. p. 291–343.
30 Tilman, E.A., Tilman, D., Crawley, M.J., and Johnston, A. E. 1999. Biological weed control via nutrient competition: Potassium limitation of dandelions. Ecological Applications 9:103–111.
31 Frederick, S. and Loewenstein, G. 2002. Time discounting and time preference: A critical review. Journal of Economic Literature 40:351–401.
32 Roschewitz, I., Gabriel, D., Tscharntke, T., and Thies, C. 2005. The effects of landscape complexity on arable weed species diversity in organic and conventional farming. Journal of Applied Ecology 42:873–882.
33 José-María, L. and Sans, F.X. 2011. Weed seedbanks in arable fields: Effects of management practices and surrounding landscape. Weed Research 51:631–640.
34 Bàrberi, P., Burgio, G., Dinelli, G., Moonen, A.C., Otto, S., Vazzana, C., and Zamin, G. 2010. Functional biodiversity in the agricultural landscape: Relationships between weeds and arthropod fauna. Weed Research 50:388–401.
35 Evans, D.M., Pocock, M.J.O., Brooks, J., and Memmott, J. 2011. Seeds in farmland food-webs: Resource importance, distribution and the impacts of farm management. Biological Conservation 144:2941–2950.
36 Mt. Pleasant, J. and Schlather, K.J. 1994. Incidence of weed seed in cow (*Bos* sp.) manure and its importance as a weed source for cropland. Weed Science 8:304–310.
37 Davis, A., Renner, K., Sprague, C., Dyer, L., and Mutch, D. 2005. Integrated Weed Management: 'One Year's Seeding...'. Michigan State University Extension, East Lansing, MI.
38 Mohler, C.L. and Johnson, S.E. 2009. Crop Rotation on Organic Farms: A Planning Manual. Natural Resource, Agriculture, and Engineering Service, Ithaca, NY.
39 Pfeiffer, E.E. 2008. Weeds and What They Tell. Biodynamic Farming & Gardening Association, Oaks, PA.
40 Walters, C. 1999. Weeds: Control Without Poisons. Acres U.S.A., Austin, TX.

41 Di Tomaso, J.M. 1995. Approaches for improving crop competitiveness through the manipulation of fertilization strategies. Weed Science 43:491–497.
42 Kopittke, P.M. and Menzies, N.W. 2007. A review of the use of the basic cation saturation ratio and the 'ideal' soil. Soil Science Society of America Journal 71:259–265.
43 Schonbeck, M. 2000. Balancing soil nutrients in organic vegetable production systems: Testing Albrecht's base saturation theory in southeastern soils. Organic Farming Research Foundation Information Bulletin 10:17.
44 Kelling, K.A., Schulte, E.E., and Peters, J.B. 1996. One hundred years of Ca: Mg ratio research. New Horizons in Soil Science Series 8. Department of Soil Science, University of Wisconsin-Madison, Madison, WI.
45 Warwick, S.L. and Sweet, R.D. 1983. The biology of Canadian weeds. 58. *Galinsoga parviflora* and *G. quadriradiata* (= *G. ciliata*). Canadian Journal of Plant Science 63:695–709.
46 Ullrich, S.D., Buyer, J.S., Cavigelli, M.A., Seidel, R., and Teasdale, J.R. 2011. Weed seed persistence and microbial abundance in long-term organic and conventional cropping systems. Weed Science 59:202–209.
47 Smith, R.G., Gareau, T.P., Mortensen, D.A., Curran, W.S., and Barbercheck, M.E. 2011. Assessing and visualizing agricultural management practices: A multivariable hands-on approach for education and extension. Weed Technology 25:680–687.
48 Gallagher, R.S., Luschei, E.C., Gallandt, E.R., and DiTommaso, A. 2007. Experiential learning activities in the weed science classroom. Weed Technology 25:680–687.
49 Gareau, T.P., Smith, R.G., Barbercheck, M.E., and Mortensen, D.A. 2010. Spider plots: A tool for participatory extension learning. Journal of Extension [Online] 48. Available at Web site http://www.joe.org/joe/2010october/tt8.php (accessed June 12, 2013).
50 Mirsky, S.B., Gallandt, E.R., Mortensen, D.A., Curran W.S., and Shumway, D.L. 2010. Reducing the germinable weed seedbank with soil disturbance and cover crops. Weed Research 50:341–352.

Renewable Agriculture and Food Systems: 29(4); 334–344 doi:10.1017/S1742170513000227

Net returns and risk for cover crop use in Alabama tomato production

Leah M. Duzy[1]*, Ted S. Kornecki[1], Kipling S. Balkcom[1] and Francisco J. Arriaga[2]

[1]USDA-ARS, National Soil Dynamics Laboratory, Conservation Systems Research, 411 South Donahue Drive, Auburn, AL 36832, USA.
[2]Department of Soil Science, University of Wisconsin – Madison, 1525 Observatory Drive, Madison, WI 53706, USA.
*Corresponding author: leah.duzy@ars.usda.gov

Accepted 24 May 2013; First published online 17 July 2013 **Research paper**

Abstract

Tomato (*Solanum lycopersicum* L.) producers are faced with uncertain yields and prices, and utilizing a production system that will reduce risk while maintaining yield may keep tomato producers economically sustainable into the future. A conservation tillage production system with high biomass cover crops may be an economically viable alternative for tomato producers in Alabama. The objective of this study was to compare the economics of alternative production systems using different cover crops, such as cereal rye (*Secale cereale* L.) and crimson clover (*Trifolium incarnatum* L.), and different subsoiler shanks for fresh-market tomato production relative to a commonly used plastic mulch system to determine the preferred treatment. Gross revenues and net returns from tomato production using a rye cover crop were higher than tomato production using plastic mulch in 2 of the 4 years. For the clover cover crop, gross revenues and net returns were higher in 1 out of the 4 years. Under tomato prices and weather conditions observed during 2005–2008, the preferred treatment for a risk neutral producer was planting tomatoes into a rye cover crop with a wide shank. For a strongly risk averse producer, all cover crop treatments were preferred to plastic mulch. The use of a cover crop in tomato production has the potential to be an equally profitable, less risky alternative to plastic mulch in Alabama.

Key words: cover crops, no-till, *Solanum lycopersicum* L., subsoiler shank, tomato production

Introduction

As a result of the increased demand for locally grown foods and the growing number of farmers' markets and community-supported agriculture organizations (CSAs), the number of farm operations classified as vegetable and melon farms (North American Industry Classification System code 1112) increased in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi and South Carolina from 5657 operations in 2002 to 6287 operations in 2007[1–4]. These states comprise the southern farm production region as defined by the United States Department of Agriculture, National Agricultural Statistics Service (USDA, NASS)[5]. In Alabama, the number of vegetable and melon farms increased by 133 operations from 2002 to 2007. In 2007, Alabama had the highest number of vegetable and melon farms among states in the southern region, at 1118 operations[4].

Tomatoes (*Solanum lycopersicum* L.) were produced on 712 of the Alabama vegetable and melon farms in 2007. However, tomato production peaked in Alabama in the mid-1970s at 3764 ha, and has steadily declined over the past 30 years. Since 1999, tomato producers have, on average, planted 526 ha yr^{-1}. While the production area has declined, per hectare yield has increased from 23,453 kg ha^{-1} in 1999 to 42,095 kg ha^{-1} in 2011[4].

Vegetable production requires a high level of management to control a wide variety of pests. Producers are faced with high production costs, variable prices and unpredictable weather. One production alternative available to vegetable producers is to adopt a conservation tillage system using winter cover crops, such as cereal rye (*Secale cereale* L.) and crimson clover (*Trifolium incarnatum* L.). Conservation systems are utilized in row crop production but have not been readily adopted into vegetable production. Cover crops provide a variety of agronomic benefits that include improved soil physical properties, increased soil organic carbon, soil moisture conservation, reduced surface runoff, weed control and nutrient cycling[6–10]. Many of the agronomic benefits can be translated into economic benefits by decreasing input costs and stabilizing yield variability.

© Cambridge University Press 2013

Previous research has shown that cover crop use in tomato production is a feasible alternative to plastic mulch. Kornecki and Arriaga reported that marketable tomato yields produced using a rye or clover cover crop were greater than or equal to marketable tomato yields produced under plastic in 3 out of 4 years in Alabama[8]. Sainju et al. concluded that, in Georgia, the use of a legume cover crop increased tomato fruit yield compared with no cover crop[9]. The use of cover crops, particularly hairy vetch (*Vicia villosa* Roth.), also has the potential to increase yield by extending the harvest season[11] and producing higher yields[12,13].

While the use of a conservation system using cover crops has numerous agronomic benefits, it also has the potential to decrease production costs. Under a conservation system using cover crops, producers no longer have to purchase plastic, prepare bed, and remove plastic mulch after harvest, thereby decreasing labor needed for tomato production. Iráizoz et al. estimated technical efficiency for horticulture production in Spain, and concluded that tomato production inputs were used more efficiently when operations increased output per labor unit[14]. While the conservation system requires establishment and termination of a cover crop, less labor is needed to produce tomatoes.

The economic impact of cover crop use in tomato production is mixed in the literature. Results differ by type of cover crop and growing conditions. Kelly et al. concluded that, in Maryland from 1991 to 1993, returns were higher in a hairy vetch system than in a plastic system[15]. The hairy vetch system produced higher yields with an extended harvest season. In other research conducted in Maryland, Wu et al., using data for 1997–1999, stated that revenue and net returns for a hairy vetch system as compared to a plastic system were varied, depending on growing conditions[16]. Research in Virginia conducted between 1998 and 1999, produced similar results with limited economic viability of organic mulch in tomato production as compared to plastic mulch[17]. Kelly et al. and Wu et al. both used a safety-first criterion (SFC) to examine production risk; however, the results were mixed[15,16]. Kelly et al. reported that hairy vetch is the least risky alternative under the given study conditions[15], while Wu et al. showed plastic mulch had the lowest economic risk[16].

Assuming that producers accept different levels of economic risk, it is important to evaluate production treatments relative to risk, along with net returns. For example, a treatment may have the highest net return as well as the highest level of economic risk. Most previous tomato literature applies the SFC to analyze risk. One alternative to the SFC for conducting risk analysis is to compare estimated net returns for the production alternatives for different risk aversion levels using the stochastic efficiency with respect to a function (SERF) method[18], utilizing the Simulation and Econometrics to Analyze Risk (SIMETAR) software[19] to simulate net return, yield and price distributions. This method has been applied to other agriculture-related topics in previous literature, such as comparing the economic performance of different tillage systems, farm policies, rental arrangements and integrated weed management alternatives[20–26].

Tomato production is a relatively small portion of agricultural sales in Alabama and across the Southeast; however, demand for locally grown vegetables is increasing[27,28]. Tomato producers are faced with uncertain yields and prices, and utilizing a production system that will reduce economic risk while maintaining yield may keep tomato producers economically sustainable into the future. A conservation production system with high biomass cover crops may be an economically viable alternative for tomato producers in Alabama. The objective of this study was to estimate the profitability of alternative production systems using different cover crops (cereal rye and crimson clover) and different subsoiler shanks for fresh-market tomato production relative to a commonly used plastic mulch system, and to determine the preferred treatment using risk analysis.

Materials and Methods

Field experiment

The study was conducted during the 2005–2008 growing seasons at the North Alabama Horticultural Research Station (NAHRS) in Cullman, AL on a Hartselle fine sandy loam soil (fine-loamy, siliceous, sub-active, thermic Typic Hapludults). The experimental design was a split plot with four treatment replications, and it was initiated in the fall of 2004. The cover treatment was comprised of three cover types: plastic mulch, cereal rye and crimson clover. For each cover crop (cereal rye and crimson clover) treatment, three subsoil shanks treatments were applied: no shank, slim shank and wide shank. Each treatment option was compared to the plastic mulch treatment, which is the typical method used in tomato production in Alabama. The plots were 2.8 m wide and had a single row of tomatoes in the middle.

Each fall (2004–2007) cover crops were planted with a no-till drill (AGCO-TYE Grain Drill, Model 124-530X, Duluth, Georgia, USA) in rows 18 cm apart in plots 6.1 m long. The cover crops were planted on October 28, October 30, October 19, and November 2 in 2004, 2005, 2006 and 2007, respectively. Cereal rye was seeded at a rate of 101 kg ha^{-1}, and crimson clover was seeded at 28 kg ha^{-1}. Each spring (2005–2008), nitrogen was applied to the cereal rye plots at a rate of 67 kg ha^{-1}. The winter cover crops were terminated on April 8, April 12, April 9 and April 17 in 2005, 2006, 2007 and 2008, respectively, with one pass with a mechanical roller crimper, followed by a supplemental chemical application of glyphosate at a rate of 1.1 kg ha^{-1} (a.i.). The roller crimper was 2.8 m wide and consisted of a round drum with equally spaced blunt,

Table 1. Average experimental yields at the NAHRS in Cullman, AL compared to average Alabama production yields, 2005–2008 (USDA, 2012b).

	Experimental yield	Production yield
Year	boxes ha^{-1}	
2005	3634.32	3287.91
2006	3589.07	3553.07
2007	4261.75	4083.38
2008	4397.86	4030.35

straight, steel bars around the drum's circumference and across the drum's length. The cover crops were terminated at the early milk stage for rye and the full flowering stage for clover. Cover crop termination was completed approximately 3 weeks before transplanting tomatoes to eliminate the potential for competition for water and nutrients between the cash crop and the cover crop. Tomato cultivar Florida 47 seedlings were transplanted on May 4, May 15, May 2 and May 1 in 2005, 2006, 2007 and 2008, respectively. Fourteen seedlings per plot (38 cm spacing between plants) were planted using a modified RJ No-Till transplanter (RJ Equipment, Blenhiem, ON, Canada). The experiment is described in detail by Kornecki and Arriaga[8].

Tomatoes were harvested on a weekly basis from July 2 to August 15, 2005, from August 3 to August 23, 2006, from July 24 to August 20, 2007, and from July 21 to August 18, 2008. Marketable yields are used in this study, which does not include damaged or diseased fruit. The fruit were graded by size (small, medium, large and extra-large). The tomato yields presented in this paper are experimental yields, and are potentially higher than yields realized by the average tomato producer in Alabama. However, as shown in Table 1, the average experimental yields were consistent with average yields in Alabama in each of the 4 years of the study. Although the average experimental yields were higher than average production yields in each year, production yields were 90% or greater of the average experimental yields. The largest difference between the two yields (367.51 kg ha^{-1}) occurred in 2008.

Economic analysis

For the purposes of this analysis, profitability was defined by net returns. Net returns were calculated as the difference between gross revenues and production costs for each treatment on a dollar per hectare basis. Gross revenues were calculated based on the average weekly dollar per box price for tomatoes based on grades (small, medium, large and extra-large) at the terminal market in Atlanta, Georgia[29]. The weight of a box was 11.34 kg. Low- and high-end prices were reported for each grade category from different suppliers (domestic suppliers aggregated by State). Prices from international

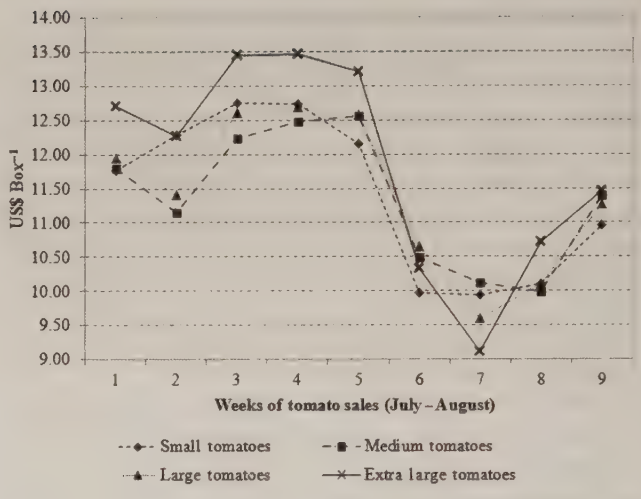


Figure 1. Weekly tomato prices from July to August at Atlanta, Georgia (Terminal Market) averaged over 2005, 2006, 2007 and 2008[27].

suppliers (such as Mexico) were not considered. The low-end tomato prices by size averaged over 2005–2008 are presented in Fig. 1. All prices were indexed to 2008 US$ using the Gross Domestic Product (GDP) Inflator. The average low-end price across all sizes and periods of harvest was 11.51 US$ box^{-1}, which is more reflective of the average marketing year price received by producers in Alabama from 2005 to 2008 for fresh market tomatoes across all sizes[4] (7.80 US$ box^{-1}). Week 1 corresponds to the first week of July and week 9 corresponds to the last week of August regardless of year. Prices for all sizes of tomatoes peak during the fourth and fifth weeks and decline throughout August and start to increase again at the end of the nine-week period. The periods of harvest (period 1 through period 6) in this study correspond with weeks 4 to 9 in Fig. 1.

Productions costs for the three types of cover (plastic, cereal rye and crimson clover) were derived from 2009 tomato enterprise budgets[30] and are presented in Table 2. Input prices represent 2008 input prices. Three types of production costs were considered: costs that were constant across all types of cover, costs that differed by type of cover and yield-dependent costs. The planting rate of tomatoes, applications of fertilizer and pesticides, and irrigation rates did not differ among plastic, cereal rye and crimson clover cover. All experimental plots received the same amount of fertilizer, amounts and types of pesticides, and amounts of irrigation water. Although these inputs were held constant across all treatments, there is the potential for the use of cover crops to impact (either positively or negatively) the amount of fertilizer, pesticides and irrigation needed in tomato production; however, these effects were not considered in this study. The tillage system, method of planting, post-harvest activities and interest on operating capital varied by treatment, and were based on the experimental design. Machinery costs were based on variable and fixed costs,

Table 2. Total production costs (US$ ha^{-1}) for staked fresh-market tomatoes (MSU, 2009).

Production costs	Plastic	Cover crop	
		Rye	Clover
Production costs differing by treatment		US$ ha^{-1}	
Cover crop establishment and termination	0	439	291
Chisel plow	19	0	0
Disk harrow	37	0	0
Plastic mulch	721	0	0
Planting tomatoes	237	232	232
Mulch lifter	46	0	0
Mulch cleanup labor	312	0	0
Interest on operating capital	413	392	388
Total	1784	1063	911
Production costs based on yield			
Custom tomato harvest	4199	4093	3772
Labor for grading and packing	7063	6885	6345
Tomato boxes	6467	6304	5809
Total	17,728	17,282	15,926
Production costs constant across treatments			
Tomato plants, fertilizer, pesticides, irrigation and other items		12,412	
Total production costs (excluding land rent)	31,924	30,757	29,248
Average yield scenario (11.43 kg boxes ha^{-1})	4199	4093	3772

and machinery for field operations was sized to represent typical machinery used by small vegetable producers in Alabama. The costs associated with tomato boxes, custom harvesting, and labor for grading and packing varied with the tomato yield of each treatment. Since management costs, land rent and depreciation on buildings can be substantially different among producers, they were not included in the production costs.

While plastic mulch is expensive and labor intensive, establishing a high-residue cover crop on a small surface is not without expense. As shown in Table 2, the difference in production costs, based on average yields, between plastic mulch and a rye cover crop is 1167 US$ ha^{-1} and between plastic mulch and a clover cover crop is 2676 US $ ha^{-1}. The cost to establish a rye cover crop is higher than the cost to establish the clover cover crop by 1509 US $ ha^{-1} due to lower cover crop seed costs for clover and the application of nitrogen fertilizer to the rye cover crop. Moving to a cover crop system also reduces labor needs associated with plastic mulch installation, removal and disposal. There are additional production activities that may be impacted by adopting a conservation system in place of plastic mulch, such as the ability to meet supply requirements and/or the timely planting of subsequent crops; however, these were not considered as part of this analysis. Producers should consider all aspects of their operation prior to adopting different production systems and/or technology.

Data were analyzed using SAS PROC GLIMMIX[31]. The dependent variable was annual net returns and net returns by harvest period, both measured in US$ ha^{-1}. Plastic mulch was the check treatment, and a binary variable (control) was generated to allow for comparisons between plastic mulch and the other main effects. The control, cover, shank, and the interaction between cover and shank were considered fixed effects. Replication and the interaction between replication and cover were considered random effects. Data were analyzed separately by year, following Kornecki and Arriaga[8]. Multiple comparison tests for differences between the control binary variable and treatments were identified using the Dunnett's test and a significance level of $P=0.10$.

A stochastic simulation model was used to generate net returns for each treatment based on simulated tomato yields for each treatment for producing tomatoes, as well as tomato price. SIMETAR[18] was employed to estimate the Gray, Richardson, Klose and Schumann (GRKS) distributions for yield using experimental data[32–34] and empirical distributions for price. The GRKS distribution is similar to triangular distribution, and is useful when there are minimal input data. Like multivariate empirical (MVE) distribution[35], it is a closed form distribution, eliminating the possibility of values outside of a reasonable range. The minimum, median and maximum were needed to estimate the GRKS distribution. For tomato yield, the minimum, median and maximum yields from the 16 yield observations (four replications/production alternative for 4 years) for each production alternative were used in fitting the GRKS distributions.

Empirical distributions for price were estimated using the average low-end weekly price per box for tomatoes

Table 3. Gross revenues and net returns by year, cover and shank treatment as compared to plastic mulch for tomato production.

Main effects		Gross revenues (US$ha^{-1})				Net returns (US$ha^{-1})			
		2005	2006	2007	2008	2005	2006	2007	2008
Cover	Plastic mulch[1]	31,867	43,434	46,279	62,027	4819	11,296	14,837	24,953
	Rye	38,646	36,717	48,651	48,952***[2]	9790	8108	16,118	15,917***
	Clover	40,026	34,862	44,495	42,430***	10,562	7300	13,991	12,966***
Shank	No shank	39,063	34,972	47,913	45,680***	9999	7267	15,785	14,646***
	Slim shank	35,336	38,636	45,935	46,972***	7805	9371	14,643	15,383***
	Wide shank	43,609	33,761*	45,871	44,421***	12,724	6475	14,736	13,295***

[1] The rye and clover main effects, as well as the shank main effects, are compared to the industry standard (plastic mulch). The gross revenues and net returns for plastic mulch, cover and shank effects are the totals.
[2] *,**,*** Significantly different at $P \leq 0.10, 0.05$ or 0.01, respectively, from plastic mulch.

based across all grades (small, medium, large and extra-large) at the terminal market in Atlanta, Georgia[29]. For comparison purposes, net returns were generated based on MVE distributions for price using the average high-end weekly price per box. Net returns were also simulated using the high-end price distribution. One thousand iterations of net returns, yields and price were simulated using GRKS and empirical distributions, respectively. Three thousand iterations were also simulated; however, the means and variances were not statistically different at the 5% probability level from the means and variances simulated with 1000 iterations, based on the *t*-test and *F*-test, respectively.

Tomato production alternatives were ranked using SERF under a negative exponential utility function, which compares a set of production alternatives based on the certainty equivalents (CE) over a range of absolute risk aversion coefficients (ARACs) or risk attitudes. The CE for a given treatment is the monetary value that would make a producer indifferent between that treatment and another treatment. The most preferred treatment has the largest CE. These estimates are an approximation and should not be considered precise. Their precision is based on the accuracy of the utility function and probability distributions[36]. The ARAC value corresponds to the level of risk aversion of the producer. Following Hardaker et al., the absolute risk aversion was the relative risk aversion divided by wealth, where wealth was the average simulated net return over all production alternatives[19]. The lower ARAC value is assumed to be zero (risk neutral). The upper bound (risk averse) is calculated as four (very risk averse) divided by the average simulated net return over all treatments (15,769 US$ ha^{-1}). In this study, the upper ARAC value equals 0.00025. The difference between the CE values at a given ARAC level is the risk premium, which is the minimum amount a producer would have to receive to decide to convert to a more risky alternative from a less risky alternative.

Results and Discussion

Gross revenues and net returns

In general, there was a lack of statistical significance ($P \leq 0.10$) across all years and treatments. The control binary ($P < 0.001$ for gross revenue and net return) and cover ($P = 0.009$ for gross revenue and $P = 0.0582$ for net return) were statistically significant in 2008. The control binary ($P = 0.0631$) was statistically significant in 2006, and cover ($P = 0.0853$) was statistically significant in 2007 for gross revenue. The only interaction that was statistically significant was the interaction between cover crop and shank in 2007 for both gross revenue and net returns ($P = 0.0322$ and $P = 0.0384$, respectively). Given the lack of significance for the interaction term, the primary focus of the following discussion is on the main effects for treatments. The lack of statistical significance is similar to the results presented by Wu et al.[16], and is consistent with the results presented by Kornecki and Arriaga[8].

Table 3 presents the gross revenues and net returns between plastic mulch and the main effects in 2005 through 2008. In 2 out of the 4 years, gross revenues and net returns were higher for the rye cover crop than for plastic mulch; however, these differences were not significantly significant. Net returns for plastic mulch (24,953 US$ ha^{-1}) were higher than rye and clover (15,917 US$ ha^{-1} and 12,966 US$ ha^{-1}, respectively) in 2008. The first year of the experiment (2005) was the only year where net returns were higher for clover (10,562 US$ ha^{-1}) than for plastic mulch (4819 US$ ha^{-1}). The rye treatment produced higher net returns than the clover treatment in 3 out of the 4 years; however, the difference (2951 US$ ha^{-1}) was only significant ($P = 0.0582$) in 2008. Net returns were higher in 2007 and 2008 than in 2005 and 2006 over all cover treatments. Kornecki and Arriaga[8] attributed lower yields in 2005 to unusually low temperatures after planting on May 4, 2005. Flowering and maturing was delayed in 2006 due to an extended period

Table 4. Difference in gross revenue between plastic mulch and the cover/shank treatments for tomato production by harvest period.

			Harvest period[1]					
			P1	P2	P3	P4	P5	P6
Year	Cover	Shank	Gross revenue (US$ha^{-1})[2]					
2005	Plastic mulch[3]		670	1996	15,755	8589	4857	0
	Rye	No shank	137	1384	5488	−2462	−826	0
	Rye	Slim shank	−15	685	7593	2078	−2371	0
	Rye	Wide shank	1047	1943	9229	1942	−1360	0
	Clover	No shank	255	371	5787	1765	2492	0
	Clover	Slim shank	654	−563	5225	−2569	377	0
	Clover	Wide shank	67	808	5451	2979	1378	0
2006	Plastic mulch		0	0	7755	24,629	9066	1985
	Rye	No shank	0	0	−1757	−8017*[4]	432	2045
	Rye	Slim shank	0	0	−1685	−3165	890	5
	Rye	Wide shank	0	0	−4152	−6692	1416	528
	Clover	No shank	0	0	353	−7237	−3541	793
	Clover	Slim shank	0	0	−583	−6098	−1.699	2.738
	Clover	Wide shank	0	0	1533	−12,322***	−0.181	0.523
2007	Plastic mulch		0	19,590	14,269	7062	3.645	1.713
	Rye	No shank	0	−11,589***	−275	4414**	9808***	5396***
	Rye	Slim shank	0	−10,852***	−2423	2540	6187**	2238
	Rye	Wide shank	0	−7292**	3665	2003	2709	588
	Clover	No shank	0	−8292**	−2807	746	3450	2416
	Clover	Slim shank	0	−6692*	156	3533	2826	1799
	Clover	Wide shank	0	−8893**	−1764	3116	2683	2369
2008	Plastic mulch		2391	24,999	28,600	4393	1644	0
	Rye	No shank	−1805***	−16,717***	−9439**	9255***	3986***	0
	Rye	Slim shank	−1820 ***	−15,836***	−8589**	9193***	5078***	0
	Rye	Wide shank	−2318***	−22,882***	−8382**	15,905***	5148***	0
	Clover	No shank	127	−11,098**	−8910**	1003	903	0
	Clover	Slim shank	49	−13,119***	−6366	495	806	0
	Clover	Wide shank	−1205*	−16,817***	−10,037***	3240	2136	0

[1] P1, P2, P3, P4, P5, and P6 correspond to the six-week period beginning the fourth week of July and ending the last week of August.
[2] A negative value means that the gross revenue for the treatment was less than the control, while a positive number indicates that gross revenues were greater than the control. A zero value means that tomatoes were not harvested in that period.
[3] The rye and clover main effects, as well as the shank main effects, are compared to the industry standard (plastic mulch). The gross revenues and net returns for plastic mulch are the totals, and the gross revenues and the net returns for the cover and shank effects are the difference between the effect and plastic mulch.
[4] *,**,*** Significantly different at $P \leq 0.10, 0.05$, or 0.01, respectively, from plastic mulch.

of rainfall, lower temperatures and a delayed first harvest, as compared to the other years. Although there was a drought in 2007, net returns across all three treatments were higher in 2007, as compared to 2005 and 2006.

The gross revenues and net returns for the shank treatments followed a similar pattern across years as gross revenues and net returns for the cover treatments. Net returns for no shank, slim shank and wide shank effects were statistically lower than net returns for plastic mulch ($P < 0.001$) in 2008. In the remaining years, there was no significant difference between plastic mulch and shank treatments for both gross revenue and net returns, with the exception of statistically lower gross revenues for the wide shank in 2006 ($P = 0.0801$). Of the three shank treatments, the slim shank treatment had the highest gross revenues and net returns in 2 of the 4 years.

Table 4 presents the difference in gross revenue between plastic mulch and the cover and shank production option by year and harvest period. Comparisons were made between the six production options (rye/no shank, rye/slim shank, rye/wide shank, clover/no shank, clover/slim shank, and clover/wide shank) and the industry standard (plastic mulch). Six harvest periods were considered even though tomatoes were not harvested in all six periods each year due to differing planting dates and rates of maturity. When gross revenues were analyzed by harvest period, an interesting trend emerged. In 2006, 2007 and 2008, plastic mulch had higher gross revenues in the earlier periods, and, in the later periods, the cover/shank production

Table 5. Summary statistics of simulated net returns (US$ ha^{-1}) for low-end and high-end average weekly tomato prices.

Cover	Shank	Mean[1]	SD	CV[2]	Min	Max	Prob. NR < 0[3]
Low-end average weekly tomato prices							
Plastic mulch		15,870	11,312	71.3	−11,569	59,184	6.5%
Rye	No shank	16,420	8943	54.5	−3240	50,548	1.3%
Rye	Slim shank	15,826	8872	53.1	−3146	46,776	1.8%
Rye	Wide shank	18,008	9883	54.9	−5230	53,089	1.5%
Clover	No shank	13,959	8220	58.9	−3412	47,154	2.1%
Clover	Slim shank	14,821	8317	56.1	−4153	48,557	1.2%
Clover	Wide shank	15,479	10,471	67.6	−7824	59,149	5.1%
High-end average weekly tomato prices							
Plastic mulch		21,294	13,153	61.8	−9519	75,132	2.6%
Rye	No shank	21,808	10,052	46.1	−2373	55,826	0.53%
Rye	Slim shank	21,060	9834	46.7	−1496	62,786	0.45%
Rye	Wide shank	23,602	10,609	44.9	−2709	64,644	0.66%
Clover	No shank	18,911	9229	48.8	−1875	61,075	0.31%
Clover	Slim shank	19,769	8839	44.7	653	59,609	0.00%
Clover	Wide shank	20,431	11,292	55.3	−6115	66,980	1.4%

[1] Summary statistics calculated from 1000 simulated iterations.
[2] CV is the coefficient of variation and is the SD divided by the mean multiplied by 100. It is a unitless measure of relative risk.
[3] Probability of receiving a negative net return.

options had higher gross revenues. This is consistent with previous literature supporting the extended harvest periods with conservation systems and cover crops[11,15,37].

Simulated net returns

Summary statistics for the simulated net returns for low-end average weekly prices are presented in Table 5. Based on the low-end average weekly prices, rye/wide shank had the largest net returns (18,008 US$ ha^{-1}) followed by rye/no shank, plastic mulch and rye/slim shank (16,420, 15,870 and 15,826 US$ ha^{-1}, respectively). Clover/no shank had the lowest net returns (13,959 US$ ha^{-1}). The return variability, as measured by the CV, was the lowest for rye/slim shank (CV = 53.1), followed by rye/no shank (CV = 54.5). Plastic mulch (CV = 71.3) had the largest return variability, as well as the greatest probability of having negative net returns (6.5%). Clover/wide shank had the second largest return variability (CV = 67.6) and one of the largest probabilities of having negative net returns (5.1%). Rye/no shank and clover/slim shank had the smallest probability of having negative net returns (1.3 and 1.2%, respectively).

CE and risk premiums to cover crops

CE and risk premiums based on low-end average weekly tomato prices were presented by treatment for various ARACs in Table 6. When ARAC equaled zero, CE equaled mean net returns. CE declined as ARAC levels increased (as producers became more risk averse). Rye/wide shank was the most preferred treatment for producers with ARAC levels less than 0.00025. As risk aversion increased, plastic mulch became the least preferred treatment, followed by clover/wide shank and clover/no shank. At all levels of risk, at least one treatment that included a cover crop was preferred over the more common plastic. Rye/wide shank and rye/no shank were preferred to plastic mulch at all ARAC levels.

The risk premiums for rye/wide shank and rye/no shank were positive across all ARAC levels, as shown in Table 6, implying monetary benefits to tomatoes planted into a rye cover crop using a wide shank were greater than monetary benefits of plastic mulch. For example, a risk neutral (ARAC = 0) producer would have to be paid 551 US $ ha^{-1} to switch from rye/no shank to plastic mulch, while a risk averse producer (ARAC = 0.00025) would have to be paid 4173 US$ ha^{-1} to switch from rye/no shank to plastic mulch. For risk neutral producers, risk premiums for rye/slim shank, clover/no shank, clover/slim shank and clover/wide shank were negative, implying monetary benefits to plastic mulch were greater than the monetary benefit to tomatoes planted into these treatments. The risk premiums for all treatments relative to plastic mulch increased as risk aversion increased. For all treatments, the monetary benefits of adopting a cover crop were positive at the highest level of risk aversion as compared to plastic mulch.

SERF method

Figure 2 presents the SERF results across ARACs ranging from 0 to 0.00025 (or risk neutral to strongly risk averse) relative to plastic mulch based on low-end average weekly tomato prices. According to Hardaker et al., the risk preferred treatment was the treatment with the highest risk premium value at any given point on the graph[18]. The SERF efficient set contained rye/wide shank for producers

Table 6. Net returns CE and plastic mulch risk premiums by treatment for various ARAC.

		ARAC					
		0.00000	0.000042	0.000094	0.000146	0.000198	0.00025
Cover	Shank	CE (US$ha^{-1})					
Plastic mulch		15,870	13,409	10,796	8578	6682	5052
Rye	No shank	16,420	14,838	13,095	11,600	10,322	9225
Rye	Slim shank	15,826	14,275	12,582	11,140	9911	8858
Rye	Wide shank	18,008	16,098	14,041	12,296	10,794	9484
Clover	No shank	13,959	12,659	11,279	10,096	9062	8149
Clover	Slim shank	14,821	13,472	12,022	10,788	9721	8782
Clover	Wide shank	15,479	13,365	11,132	9266	7692	6353
		Risk premium relative to plastic mulch (US$ha^{-1})					
Rye	No shank	551	1428	2299	3022	3641	4173
Rye	Slim shank	−44	866	1786	2562	3230	3806
Rye	Wide shank	2138	2689	3245	3717	4112	4432
Clover	No shank	−1911	−750	483	1518	2380	3097
Clover	Slim shank	−1049	63	1226	2209	3039	3731
Clover	Wide shank	−391	−44	336	687	1010	1301

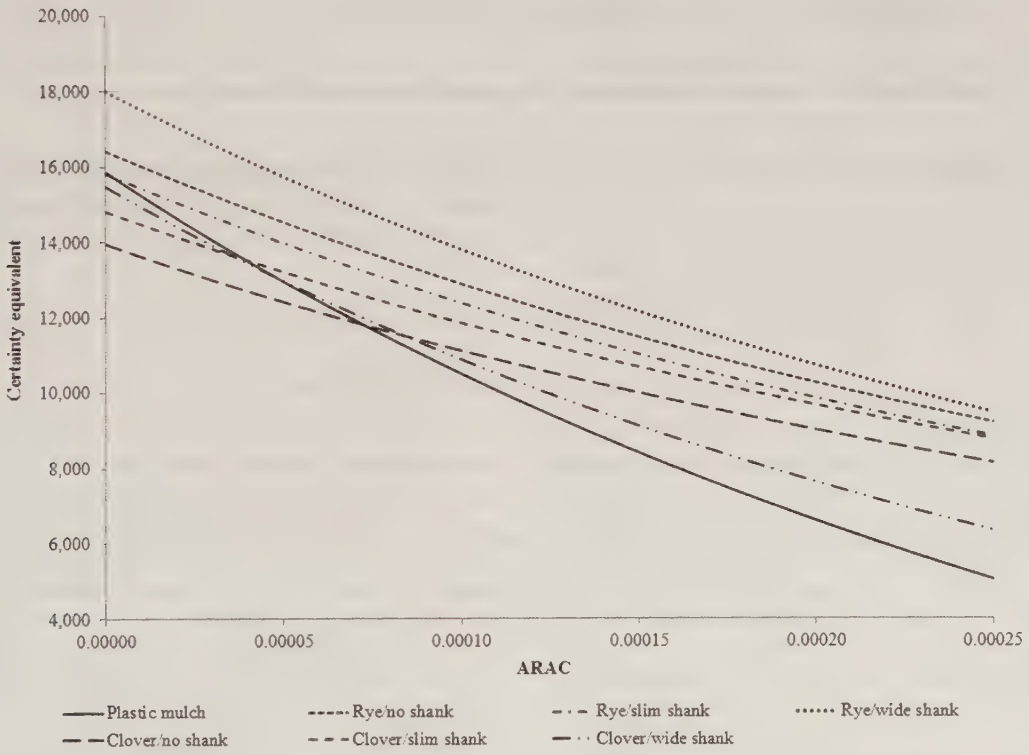


Figure 2. Risk premiums for the most risk-preferred tomato production treatment relative to plastic mulch.

across all ARAC levels. Rye/no shank was also preferred to plastic mulch across all ARAC levels, and rye/slim shank at ARAC levels greater than 0. For ARAC levels >0.000073, all six cover crop treatments were preferred to plastic mulch. The CE gap between the cover crop/shank treatments and plastic mulch widened with increasing levels of risk; however, the CE gap between cover crop treatments narrowed with increasing levels of risk. Therefore, risk related to net returns may have a substantial impact on a tomato producer's preference for adopting systems using a rye or clover cover crops in place of plastic mulch.

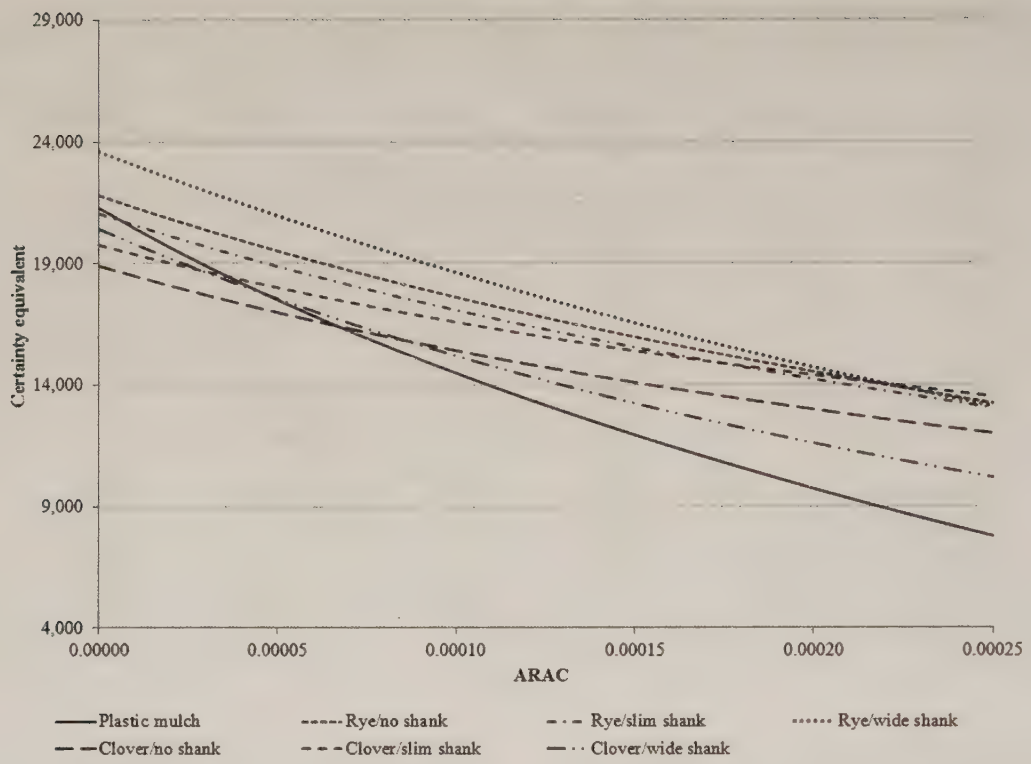


Figure 3. Risk premiums for the most risk-preferred tomato production treatment relative to plastic mulch based on high-end average weekly tomato prices.

Sensitivity analysis with respect to tomato price

Sensitivity analysis was conducted for tomato prices to investigate the results under high-end average weekly prices. The simulation net returns, as shown in Table 5, were similar to the simulation results for the low-end average weekly prices; however, the average clover/no shank (19,769 US$ ha^{-1}) was higher than for clover/slim shank (18,911 US$ ha^{-1}). Plastic mulch and clover/wide shank had the highest CV and the largest probabilities of having negative net returns. The treatments with the lowest CV were different under the high-end average weekly prices (rye/wide shank and clover/slim shank) as compared to the low-end average weekly prices (rye/no shank and rye/wide shank).

Based on Fig. 3, which presents the SERF results across ARACs ranging from 0 to 0.00025 (or risk neutral to strongly risk averse) relative to plastic mulch based on high-end average weekly tomato prices, it was clear that the results are similar with one exception. At high ARAC levels (risk-averse producers), there was little difference between the three rye cover crop treatments and the clover/slim shank treatment. Under low-end average weekly tomato prices, rye/wide shank was the preferred treatment for very risk-averse producers; however, under high-end average weekly tomato prices, clover/slim shank was the preferred alternative. Under high-end average weekly tomato prices, the overall conclusion that risk related to net returns may have a substantial impact on a tomato producer's preference for adopting systems using a rye or clover cover crop in place of plastic mulch does not change.

Conclusion

This analysis evaluated the net returns for tomato production in Alabama using two different cover crops and three different shank options in comparison to the more common plastic mulch production system. The risk efficiency of a cover crop system in tomato production was also examined using simulation and the SERF method. Based on the experimental data, gross revenues and net returns from tomato production using a rye cover crop were higher than tomato production using plastic mulch in 2 of the 4 years. For the clover cover crop, gross revenues and net returns were higher in 1 out of the 4 years. The use of a cover crop decreased production costs compared to plastic mulch, and the profitability of this system could be increased with a reduction in the cost of establishment and termination of the cover crop.

Tomato producers are faced with different production and financial situations. Their risk preferences play an important role in determining their production decisions. Under the low-end average weekly tomato prices and weather conditions during 2005–2008, the preferred treatment for a risk neutral producer was planting

tomatoes into a rye cover crop with a wide shank. For a strongly risk averse producer, all six cover crop treatments were preferred to plastic mulch. Similar conclusions were reached under high-end average weekly tomato prices. Cover crops provide less variability in yield as compared to plastic, as well as higher yields in later harvest periods. The use of a cover crop in tomato production has the potential to be an equally profitable, less risky alternative to plastic mulch in Alabama.

References

1 Darby, K., Batte, M.T., Ernst, S., and Roe, B. 2008. Decomposing local: A conjoint analysis of locally produced foods. American Journal of Agricultural Economics 90 (2):384–395.

2 Dimitri, C. 2012. Use of local markets by organic producers. American Journal of Agricultural Economics 94(2):301–306.

3 Thilmany, D.D. and Low, S.A. 2012. Will local food influence American diets? Choices 27(1). Available at Web site http://purl.umn.edu/122797 (verified June 17, 2013).

4 USDA. 2012. Quick Stats. National Agricultural Statistics Service, United States Department of Agriculture (USDA). Available at Web site http://quickstats.nass.usda.gov/ (verified June 27, 2012).

5 USDA. 2011. ARMS III Farm Production Regions Map. National Agricultural Statistics Service, United States Department of Agriculture (USDA). Available at Web site http://www.nass.usda.gov/Charts_and_Maps/Farm_Production_Expenditures/reg_map_c.asp (verified June 27, 2012).

6 Ducamp, F., Arriaga, F.J., Balkcom, K.S., Prior, S.A., van Santen, E., and Mitchell, C.C. 2012. Cover crop biomass harvest influences cotton nitrogen utilization and productivity. International Journal of Agronomy, Article ID 420624, doi: 10.1155/2012/420624. Available at Web site http://www.hindawi.com/journals/ija/2012/420624/abs/ (verified June 27, 2013).

7 Kelton, J.A., Price, A.J., and Mosjidis, J.A. 2012. Allelopathic weed suppression through the use of cover crops. In A.J. Price (ed.). Weed Control. Intech Press, Rijeka, Croatia. ISBN 978-953-51-0159-8.

8 Kornecki, T.S. and Arriaga, F.J. 2011. Impact of different cover crops and types of transplanter mounted subsoiler shanks on tomato yield. HortScience 46(5):715–720.

9 Sainju, U.M., Singh, B.P., and Whitehead, W.F. 2001. Comparison of the effects of cover crops and nitrogen fertilization on tomato yield, root growth, and soil properties. Scientia Horticulturae 91:201–214.

10 Snapp, S.S., Swinton, S.M., Labarta, R., Mutch, D., Black, J.R., Leep, R., Nyiraneza, J., and O'Neil, K. 2005. Evaluating cover crops for benefits, costs and performance within cropping system niches. Agronomy Journal 97:322–332.

11 Teasdale, J.R. and Abdul-Baki, A.A. 1997. Growth analysis of tomatoes in black polyethylene and hairy vetch production systems. HortScience 32(4):659–663.

12 Abdul-Baki, A.A., Teasdale, J.R., Goth, R.W., and Haynes, K.G. 2002. Marketable yields of fresh-market tomatoes grown in plastic and hairy vetch mulches. HortScience 37(6):878–881.

13 Campiglia, E., Mancinelli, R., Radicetti, E., and Caporali, F. 2010. Effect of cover crops and mulches on weed control and nitrogen fertilization in tomato (*Lycopersicon esculentum* Mill.). Crop Protection 29:354–363.

14 Iráizoz, B., Rapún, M., and Zabaleta, I. 2003. Assessing the technical efficiency of horticultural production in Navarra, Spain. Agricultural Systems 78:387–403.

15 Kelly, T.C., Lu, Y., Adbul-Baki, A.A., and Teasdale, J.R. 1995. Economics of a hairy vetch mulch system for producing fresh-market tomatoes in the Mid-Atlantic region. Journal of the American Society for Horticultural Science 120(5):854–860.

16 Wu, S., Liu, Y., Mills, D.J., Coffman, C.B., and Teasdale, J.R. 2002. Economic evaluation of alternative production systems for fresh-market tomatoes in the Mid-Atlantic Region. Journal of Vegetable Crop Production 8(1):91–107.

17 Sterrett, S.B., Hohlt, H.E., and Savage, C.P. Jr. 2005. Alternative management strategies for tomato affect cultural and economic sustainability. HortScience 40(3):602–606.

18 Richardson, J.W., Schumann, K.D., and Feldman, P.A. 2011. SIMETAR: Simulation and Econometrics to Analyze Risk. Simetar, Inc., College Station, TX.

19 Hardaker, J.B., Richardson, J.W., Lien, G., and Schumann, K.D. 2004. Stochastic efficiency analysis with risk aversion bounds: A simplified approach. Australian Agricultural and Resource Economics 48(2):253–270.

20 Archer, D.W. and Reicosky, D.C. 2009. Economic performance of alternative tillage systems in the Northern Corn Belt. Agronomy Journal 101:296–304.

21 Lien, G., Hardaker, J.B., and Flaten, O. 2007. Risk and economic sustainability of crop farming systems. Agricultural Systems 94:541–552.

22 Smith, E.G., O'Donovan, J.T., Henderson, W.J., Turkington, T.K., McKenzie, R.H., Harker, K.N., Clayton, G.W., Juskiw, P.E., Lafond, G.P., Grant, C.A., Brandt, S., Edney, M.J., Johnson, E.N., and May, W.E. 2012. Net return for malting barley production in Western Canada as influenced by production strategies. Agronomy Journal 104:1374–1382.

23 Upadhyay, B.M., Smith, E.G., Clayton, C.W., Harker, K.N., and Blackshaw, R.E. 2006. Economics of integrated weed management in herbicide-resistant canola. Weed Science 54(1):138–147.

24 Varner, B.T., Epplin, F.M., and Strickland, G.L. 2011. Economics of no-till versus tilled dryland cotton, grain sorghum, and wheat. Agronomy Journal 103:1329–1338.

25 Watkins, K.B., Hill, J.L., and Anders, M.M. 2008. An economic risk analysis of no-till management and rental agreements in Arkansas rice production. Journal of Soil and Water Conservation 63(4):242–249.

26 Williams, J.R., Llewelyn, R.V., Pendell, D.L., Schlegel, A., and Dumler, T. 2010. A risk analysis of converting Conservation Reserve Program acres to a wheat-sorghum-fallow rotation. Agronomy Journal 102:612–622.

27 Brown, C. and Miller, S. 2008. The impacts of local markets: A review of research on farmers markets and community supported agriculture (CSA). American Journal of Agricultural Economics 90:1298–1302.

28 Wixson, S.E., Katchova, A.L., Woods, T.A., and Hu, W. 2011. The role of specialty food stores and farmers' markets in the procurement of local foods. In Selected Paper Presented at the Southern Agric. Econ. Assoc. Annual Meeting, Corpus Christi, TX, February 5–8, 2011. Available at Web site. http://purl.umn.edu/97969 (accessed June 24, 2013).
29 USDA. 2012. Fruit and Vegetable Market News. Agricultural Marketing Service, United States Department of Agriculture (USDA). Available at Web site http://www.marketnews.usda.gov/portal/fv (verified June 25, 2012).
30 MSU. 2009. Traditional and organic vegetables 2009 planning budgets. Budget Report 2009–01. Department of Agricultural Economics, Mississippi State University (MSU).
31 SAS Institute. 2008. SAS Enterprise Guide. Release 4.2. SAS Inst., Cary, NC.
32 Bishop, C.D., Curtis, K.R., and Kim, M. 2010. Conserving water in arid regions: Exploring the economic feasibility of alternative crops. Agricultural Systems 103:535–542.
33 Ribera, L.A. and Cattaneo, M. 2008. Economics of variety selection for cotton cultivars in the Lower Rio Grande Valley, Texas. Journal of Extension [Online] 46(5): 5RIB3. Available at Web site http://www.joe.org/joe/2008october/rb3.php (accessed June 24, 2013).
34 Rodríguez, H.G., Popp, J., Thomsen, M., Friedrich, H., and Rom, C.R. 2012. Economic analysis of investing in open-field or high tunnel primocane-fruiting blackberry production in northwestern Arkansas. HortTechnology 22 (2):245–251.
35 Richardson, J.W., Klose, S.L., and Gray, A.W. 2000. An applied procedure for estimating and simulating multivariate empirical (MVE) probability distributions in farm-level risk assessment and policy analysis. Journal of Agricultural and Applied Economics 32(2):299–315.
36 Harwood, J., Heifner, R., Coble, K., Perry, J., and Somwaru, A. 1999. Managing Risk in Farming: Concepts, Research, and Analysis. United States Department of Agriculture, Economic Research Service, Washington, DC.
37 Abdul-Baki, A.A., Teasdale, J.R., Korcak, R., Chitwood, D.J., and Huettel, R.N. 1996. Fresh-market tomato production in a low-input alternative system using cover-crop mulch. HortScience 31:65–69.

Renewable Agriculture and Food Systems: 29(4); 345–354 doi:10.1017/S1742170513000197

A multi-criteria assessment of the production and marketing systems of local mountain food

Jernej Prišenk*, Črtomir Rozman, Karmen Pažek, Jernej Turk, Zarja Bohak† and Andreja Borec

Faculty of Agriculture and Life Sciences, University of Maribor, Pivola 10, 2311 Hoče, Slovenia.
†Present address: Spodnji Gasteraj 9, 2223 Jurovski Dol, Slovenia. *Corresponding author: jernej.prisenk@um.si

Accepted 17 May 2013; First published online 24 June 2013 **Research paper**

Abstract
A multi-criteria model for a qualitative assessment of the production and marketing of local food products (LFP) from mountain areas has been developed by applying the DEX method. The development of the model was carried out and finally applied to ten local food products. The results were given in the form of a qualitative final assessment of both the production and marketing phases. By applying a plus–minus-1 analysis, the influence of various attributes on the final assessment of the LFP was examined. The main bottlenecks in the production and marketing processes were found. A sensitivity test was used to explain the influence of production and marketing on the final assessment. The results give clear directions as to which of the main attributes must be changed/improved or further developed to enable the successful promotion of local food products, which would give rise to an improved economy in mountain areas.

Key words: food products, mountain areas, multi-criteria decision model, DEX

Introduction

Local products are tied to their area of origin and are often considered to be important tools for use in maintaining local culture and traditions and fostering rural development, especially in disadvantaged and mountain areas[1]. Irrespective of many studies and definitions about local food, it has been noted that there is still no single definition of the term, although in recent years, local food has been perceived to be a growing category[2]. Indeed, several studies conducted in European countries have shown growing consumer and retailer interest in local food products (LFP)[2–6]. Irrespective of the lack of a working definition for local food, many researchers have studied the importance of LFP while using various definitions[7–10]. Many of them estimate the importance of local food to be much broader than mere consumer perception; local food also has a significant environmental and socio-economic role and is closely linked to broader rural development issues, such as sustaining local businesses, retaining money in the local economy, the presence of successors on farms, and maintaining and preserving agricultural land in mountain areas. In addition, some authors[1] hold that much empirical evidence shows that the LFP are often used as a fundamental component in the collective strategies of rural development.

In Slovenia, local food still commands no recognizable purchasing power, although the volume of research on local food has increased in recent years[11–13]. There is also no agreed-upon perspective or results that can point to the exact factors that are hampering the development of the local food concept and its delivery to consumers.

Starting from this, the first step is to study the local food production process and ascertain where in the production process the main bottlenecks exist and how they are inhibiting the development of the local food concept.

For local food products, in terms of consumer and society acceptance, we need to apply modern assessment tools that also include economic parameters that are not directly related only to quantitative values. The multi-criteria decision analysis (MCDA) in this survey was applied because the many aspects of local can behave in conflicting ways[14] (for instance, some products can be attractive for the market yet difficult to produce or vice versa). One of the most commonly used MCDA methods is the analytical hierarchical process (AHP)[15–22], which was first presented in 1980 by Saaty[16] and Multi Attribute Theory (MAUT), which was applied to agricultural systems later on, in 2010[17]. Both of these use the quantitative assessment of alternatives. In contrast to AHP and MAUT, the DEX method presented by

© Cambridge University Press 2013

Bohanec[23] uses discrete attribute (criteria) values and utility functions (UFs) in the form of 'if...then' decision rules[22]. These seem to be well-suited for dealing with 'soft' decision problems, for which qualitative scales can be more informative than quantitative scores[23,24].

In the assessment field, an MCDA is more often used as an ex-ante evaluation tool for the examination of alternative projects or strategic solutions[25]. To date, the method has been applied to solve numerous real-life decision problems in agriculture, rural development and environmental protection[15,17,21,22,26–31]. As, in this study, the focus is on the assessment of the production and marketing system of local food, MCDA was used as ex-post analysis. Other food attributes, e.g., taste, ingredients and cultural values, were not included in the survey.

Since Slovenian mountain and hilly regions are spread out over more than 70% of that nation's total area, we decided to focus our research only on Alpine and prealpine areas in Slovenia. We use the term 'local mountain food products' to avoid the dual identity of the products. In mountain areas, mountain products could be considered and sold as local products, but in non-mountain areas, mountain products are mostly considered to be special products reflecting the image of mountain areas[7]. With the term 'local mountain products', we attempted to emphasize the local origin of products, as well as local sales/local marketing channels.

For the study, we use four typical mountain food categories in Slovenia: dairy, meat, bakery and fruit. Altogether, ten food products were examined.

First, the aim of the study was to examine whether the DEX method is appropriate for the assessment of the production and marketing systems of local food. Secondly, the study aimed to determine whether the method gives clear directions for overcoming bottlenecks in both systems. The added value of the DEX methodology, as applied in our research, can be recognized in the fact that it is also a useful methodology in comparison with the MCDA methods that have already been used in food systems[21] and a suitable tool for assessments in the agro-food sector in general.

In this paper the study area and data sources are defined; this is followed by a description of the methodology and model development, then the application of the model to ten local mountain food products. The results of applying the DEX model to ten local food products, along with a discussion, are described in the next section. The paper concludes with our main findings and recommendations for further study.

Materials and Methods

Data sources

Survey input data are supported by questionnaires prepared for leaders and/or managers of projects linked to the marketing of selected local mountain foods. Altogether, 20 face-to-face interviews were carried out by well-qualified examiners between July and October 2011. As the interviews could be classified as subjective methods[8], which we considered a disadvantage for our research, the questions were mostly closed in order to make the answers more objective.

Table 1. Food product categories.

Sign of food product in the model	Food product category	Name of food product
I	Meat product 1	Zgornjesavinjski zelodec (dry meat)
II	Dried fruit	Dried fruit
III	Dairy product 3	Solčava sirnek (dairy product from fresh milk)
IV	Bakery product 2	Rye bread
V	Product from fresh fruit	Cider
VI	Dairy product 2	Bovški cheese (sheep cheese)
VII	Dairy product 1	Tolminc (cow cheese)
VIII	Cooked product	Pohorje pot
IX	Bakery product 1	Tarragon cake
X	Meat product 2	Jetrnica (sausage)

Ten marketing projects and ten LFP (Table 1) were the core of the questionnaire. The selection of each food product was linked more to its existing marketing project than to its ingredients or quality characteristics. Nevertheless, we should mention that some of examined food products, such as Tolmin cheese and Zgornjesavinjski zelodec (dry meat), already belong to the PDO (protected designation of origin) and PGI (protected geographical indication) food quality scheme. One of them is in the process of application (Bovški cheese). The rest are mountain food products that are recognized at a local level. All examined projects were supported by LEADER and realized within Local Action Groups (LAGs).

Before structuring the questionnaire, the data collection, used for building up the hierarchical tree, was performed by a focus group of five experts involved in the study section of the model development. The questionnaire was designed to gather information about each local food product, project construction and development, realization and project outcomes. The questionnaire combines two types of questions. The first type is based on empirical answers (e.g., 'the average % sales of yields produced', 'the size of the cultivated area on a farm', 'the average amount of yields produced' and 'number of farms dealing with production'), while the second type of question is based on descriptive answers (e.g., 'yes/no', 'organic/integrated/conventional type of farming').

Interview answers were further processed and, if necessary, converted into measurable quantitative parameters that were afterwards applied to a multi-criteria decision model. The model, along with the defined value scales, is presented in Figure 1.

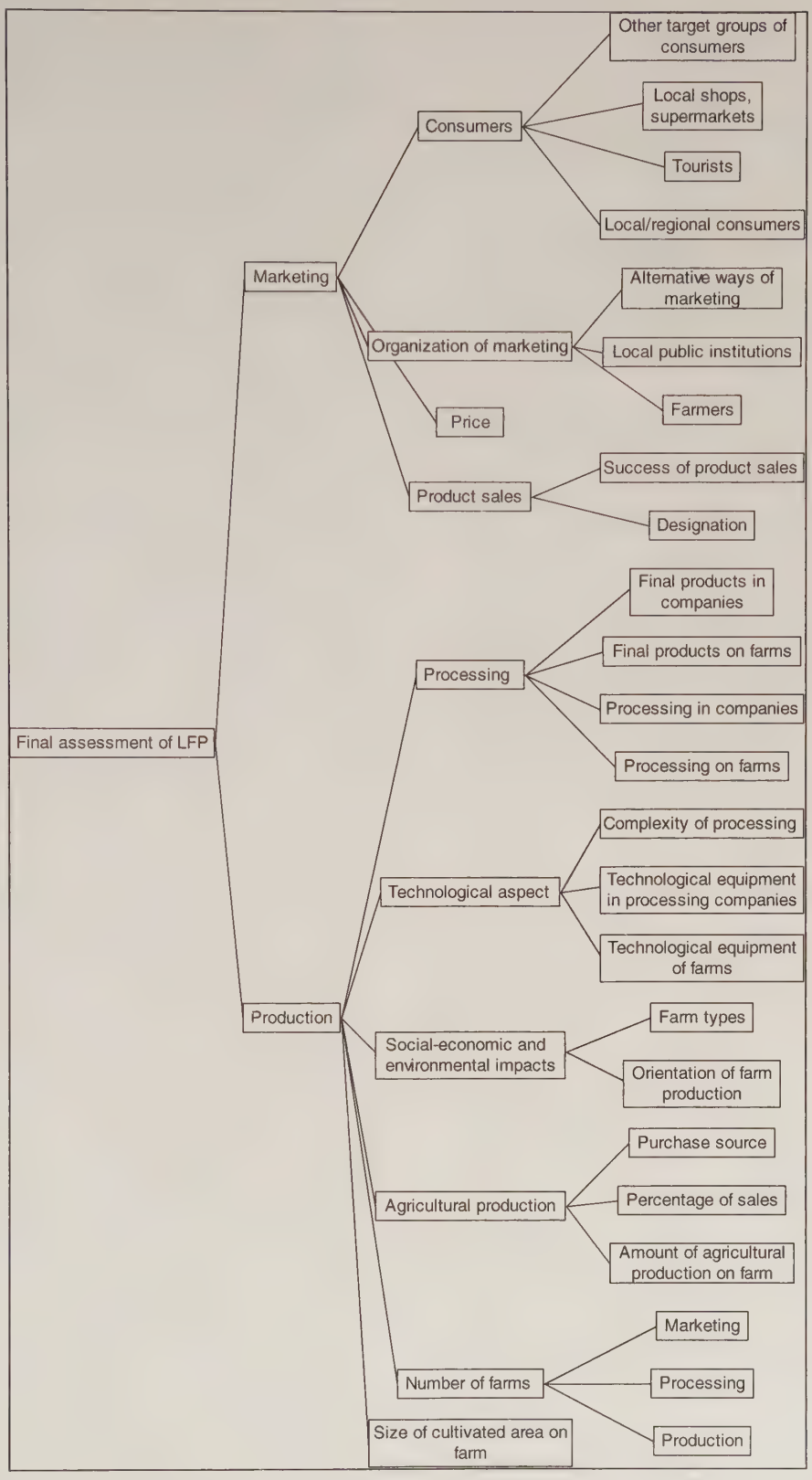


Figure 1. The hierarchy tree of the DEX multi-attribute model.

Although the interviews were the main information source, in order to gain complete findings for each local food product, historical, social and spatial backgrounds were examined, as well as the entire food chain.

Multi-attribute assessment methodology DEX

DEX is a methodology for qualitative multi-criteria decision modelling and support[18,22]. The DEX method is

Table 2. Description of steps of the DEX model and activities for each step.

Step	Activity
1. Identification of problems	The decision problem is identified and attributes tree is built (Fig. 1)
2. Identification of criteria(s)	Each sub-problem is presented as qualitative attribute with a defined value scale (Fig. 2)
3. Defining UF for each aggregate attribute	Decision rules (UFs) for each aggregate attribute are defined

implemented via the software program DEX-i[23]. The combination of Expert Systems, Machine Learning and traditional multi-criteria decision-making represents the elements of DEX methodology. The development of the DEX model is based on three typical steps, as shown in Table 2[23].

The variable values in DEX are usually represented by words (discrete values) such as 'yes or no, lower or higher, etc.' Qualitative values describe basic attributes, as well as aggregate attributes, which are, in our research, on the fifth level of hierarchy, i.e., basic attributes are aggregated to other attributes, and these attributes are aggregated to a final alternative assessment. UFs are an important part of the evaluation and decision process (described in the 'model development' section).

Model development

The majority of current multi-criteria methods (MCM) are aimed at the development of quantitative decision models[32]. The first step in MCM development is the structuring of the decision hierarchy[28]. The construction of a hierarchical tree is built up from many sub-problems (attributes) that have consequences for the final decision. Figure 1 presents the hierarchical tree of the developed model. Examining it from an abstract point of view, the left side of the model could be perceived as the 'trunk' of the tree, and the right side could be perceived as the tree's 'crown'. The attributes of the tree's 'crown' (third level attributes) are combined into aggregate attributes, which are the 'branches' (second level attributes) of the tree. These are further combined to create the 'root system' of the tree—the final assessments of local food products.

In our research, the hierarchical decision model was structured so as to have aggregate attributes on the higher level and also have aggregate attributes on the lower level. The hierarchy of the model (attributes and UFs) is based on a preliminary literature review[26,29,30], relevant research objectives and indicators of performance for local food product schemes[2,21]. The aggregation process is based on the UFs. In the DEX program, the UFs are represented by decision rules, which are acquired from the model developers[26] (more details below). The hierarchical structure of the developed model consists of two complex aggregate attributes ('Marketing' and 'Production'). The 'Marketing' attribute further consists of four sub-attributes ('Consumers', 'Price', 'Organization of Marketing' and 'Product sales').

The 'Production' aggregate attribute consists of five other aggregate attributes: 'Number of farms', 'Agricultural production', 'Social-economic and environmental impacts', 'Technological aspect' and 'Processing', and it also has one non-aggregate attribute: 'Size of cultivated area on farm'. The 'Marketing' aggregate attribute consists of the three other aggregate attributes, 'Product sales', 'Organization of marketing' and 'Consumers', and the non-aggregate attribute 'Price' on the second level. The construction of all aggregate attributes on the second level is described in Table 3.

The second step of the model development was based on a value scale definition for each sub-attribute (Fig. 2). The value scale is discrete and typically consists of words[32]. In the presented model, some attributes are on a numerical scale (i.e., 'Size of cultivated area on farm', 'Price', 'Success of product sales', etc.). With data previously inserted into MS Office Excel, the numerical values (especially basic attributes such as 'Size of cultivated areas', 'Percentage of sales', etc.) were distributed (preferentially ordered) into three-stage scales (they can also be described as *good, neutral* or *bad*), which were, after the definition of the UFs, presented in terms of qualitative values.

The next step was to define the decision rules (i.e., UFs). The decision rules describe the value of an aggregate attribute for each combination of input attributes and express the relative importance of the individual attributes[28]. The relative importance of an individual attribute is represented with a weight value. Setting the weights (49 and 51%) defines the relationship between 'Production' and 'Marketing' because they have similar impacts on the final assessment[2,33]. The authors assumed that the relative importance of the 'Production' and 'Marketing' attribute systems are in balance in the determination process of the final assessment of local food. In the survey, the weights should be 50% for both systems, but the reason for the imbalance lies in the normalization process that is automatically performed by the DEX program. This happened because some attributes' scales can have more value than others[34]. The first and last decision rules were strictly defined by experts, who set the worst (*not sufficient*) and the best (*excellent*) assessments of LFP. For example, if the assessment of production is *small* and that of marketing is *not successful*, the final assessment is *not sufficient*. The final assessment of LFP is *excellent* if the assessment of production is *large* and marketing is '$\geqq$' *successful* (Fig. 3). Some decision rules are expressed in a more complex form, such as '$\geqq$', which means *equal to or greater than*. Decision rules were defined for all aggregate attributes of the hierarchy; thus, the final sum gives 11 UFs.

Table 3. Description of aggregate attributes at the second level of the hierarchy.

Name of aggregate attribute (second level)	Name of basic attribute(s)-third level	Description of basic attribute
1.1 'Number of farms'	1.1.1 'Production' 1.1.2. 'Processing' 1.1.3. 'Marketing'	Number of active farms and/or companies dealing with 1.1.1, 1.1.2, .1.1.3. segments
1.2 'Agricultural production'	1.2.1 'Amount of agricultural production on farm'	Average amount of produced yields
	1.2.2. 'Percentage of sales'	The average (in %) sales of produced yields
	1.2.3. 'Purchase source'	Purchase source: own or/and from other producers
1.3 'Social-economic and environmental impacts'	1.3.1. 'Orientation of farm production'	Farm orientation: organic, integrated or conventional
	1.3.2. 'Farm types'	Socio-economic farm type: supplementing farms, part time farms or full time farms
1.4 'Technological aspect'	1.4.1 'Technological equipment of farms'	Quality of technological equipment on farm
	1.4.2. 'Technological equipment in processing companies'	Quality of technological equipment in processing companies
	1.4.3. 'Complexity of processing'	Complexity of food processing
1.5 'Processing'	1.5.1. 'Processing on farms'	Describes the average (in %) of agricultural yields used for local food processing on the farm
	1.5.2. 'Processing in companies'	Describes the average (in %) of agricultural yields used for local food processing in local food companies
	1.5.3. 'Final products on farms'	Amount of processed food products on farms
	1.5.4. 'Final products in companies'	Presence/no presence of processed food products in companies
2.1 'Product sales'	2.1.1. 'Designation'	Presence of protected designation(s) for local single food product
	2.1.2. 'Success of product sales'	Percentage of final local food product sales
2.2 'Organization of marketing'	2.2.1. 'Farmers'	Participation of farmers in marketing of local food product(s)
	2.2.2. 'Local public institutions'	Participation of local public institution(s) in marketing of food product(s)
	2.2.3. 'Alternative ways of marketing'	Presence of any alternative ways of marketing (e.g., internet sales)
2.3 'Consumers'	2.3.1. 'Local/regional consumers'	Presence of local/regional consumers
	2.3.2. 'Tourists'	Presence of tourists as consumers
	2.3.3. 'Local shops, supermarkets,'	Presence of food products in local shops and/or supermarkets
	2.3.4. 'Other target groups of consumers'	Consumers with special diet

Results and Discussion

The final results of the DEX-i evaluation for all food products can be seen in Figures 4 and 5.

Local mountain food products can ultimately be assessed as *excellent, successful, less successful, sufficient* or *not sufficient*. Two of the examined LFP (rye bread and dried fruit) were assessed as *sufficient* or *less successful*. These dual assessments depend on the basic attribute 'technological equipment in processing companies'. This basic attribute was indefinite because food processing is mostly performed on small-scale farms. Products Zgornjesavinjski zelodec and Tolminc received the best final assessments (*excellent*). On the production level, the products Zgornjesavinjski zelodec and Tolminc received the best assessments as well, which were described as *large*. A production level grade one step lower (*average*) was ascribed to the food products Bovški cheese and Jetrnica. Only the food product Pohorje pot was assessed as *small*. The food products Zgornjesavinjski zelodec and Tolminc cheese received the highest grade (*successful*) in regards to marketing level.

The assessments of the marketing attributes of the food products dried fruit, Solčava sirnek, rye bread, cider, Bovški cheese, tarragon cake and Jetrnica were lower as compared with the marketing assessments of other food products. To achieve the higher final marketing grades, at least two of the three marketing attributes ('Product sales,' 'Organization of marketing' and 'Consumers') must be assessed as *good, sufficient* or *large*, which is not the case

Attribute	Scale
Final assessment of LFP	**Not sufficient**; **Sufficient**; Less successful; Successful; ***Excellent***
├**Production**	**Small**; Average; ***Large***
│├Size of cultivated area on farm	**1–3 ha**; 3.1–6.5 ha; 6.6–9.1ha; ***over 9.1ha***
│├**Number of farms and companies**	**Little**; Average; ***A lot of***
││├Production	**0–150**; 151–350; ***over 350***
││├Processing	**0–150**; 151–350; ***over 350***
││└Marketing	**0–25**; 26–50; 51–75; ***over 75***
│├**Agriculture resource production**	**Small**; Average; ***Large***
││├Quantity of source production on farm	**Low**; Average; Good; ***Large***
││├Quantity of selling agricultural resources	**0–25%**; 26–50%; 51–75%; ***76–100%***
││└Type of agricultural resources	**Combined**; ***Own***
│├**Social-economic and environmental impacts**	**Bad**; Average; ***Good***
││├The way of agricultural resource production	**0–3**; 3.1–6; 6.1–18; ***over 18***
││└Type of farms	**Supplementing** ; Part time; ***Full time***
│├**Technological aspect**	**Bad**; Good; ***Excellent***
││├Technological equipment of farms	**Bad**; Average; Good; ***Excellent***
││├Technological equipment of processing companies	**Bad**; Average; Good; ***Excellent***
││└Complexity of processing process	**Complicated**; Not so complicated; ***Simple***
│└**Processing process**	**Low**; Average; Good; ***Large***
││├Processing process on farms	**0–25 %**; 26–50 %; 51–75 %; ***76–100 %***
││├Processing process in companies	**0–25 %**; 26–50 %; 51–75 %; ***76–100 %***
││├Final products on farms	**Low**; Average; Good; ***Large***
││└Final products in companies	**No**; ***Yes***
└**Marketing**	**Not successful**; Partially successful; Successful; ***very successful***
│├**Selling a product**	**Bad**; Good; ***Excellent***
││├Designation	**No designation**; Own designation; ***PDO or PGI***
││└Success of product sales	**0–30 %**; 31–60 %; 61–95 %; ***> 95%***
│├Price	**< 1%**; 1–20%; 21–50%; ***> 50%***
│├**Organization of marketing**	**Bad**; Average; Good; ***Excellent***
││├Farmers	***Yes***; **No**
││├Local public institutions	***Yes***; **No**
││└Another way of marketing	***Yes***; **No**
│└**Customers**	**Not sufficient**; Sufficient; Average; ***Large***
││├Local/regional consumers	***Yes***; **No**
││├Tourists	***Yes***; **No**
││├Chain of sales companies	***Yes***; **No**
││└Other target groups of consumers	***Yes***; **No**

Figure 2. Attribute scales for the problem observed.

Decision rules

	Production	Marketing	Final assessment of LFP
	49%	51%	
1	**Small**	**Not successful**	**Not sufficient**
2	**Small**	Partially successful	**Sufficient**
3	Average	**Not successful**	**Sufficient**
4	**Small**	Successful	Less successful
5	Average	Partially successful	Less successful
6	***Large***	**Not successful**	Less successful
7	**Small**	***Very successful***	Successful
8	Average	Successful	Successful
9	***Large***	Partially successful	Successful
10	⩾Average	***Very successful***	***Excellent***
11	***Large***	⩾Successful	***Excellent***

Figure 3. Example of decision rules for the assessment of local mountain food products.

in any of the previously mentioned food products (dried fruit, Solčava sirnek, rye bread, cider, Bovški cheese, tarragon cake and Jetrnica). Indeed, the high values of these marketing attributes are more linked to the characteristics of high-scale production than to niche local market chains.

To identify bottlenecks in both the production and marketing processes, 'Plus–minus 1' (PS-1) analysis was further applied.

Results of the 'PS-1' analysis

A 'PS-1' analysis describes changes in certain basic attributes by one degree upwards or downwards (if possible) that are independent of other attributes[23]. Dried fruit was chosen for a more detailed explanation because the final assessment was not strictly defined but could be described as *sufficient* or *less successful*. The results of the 'PS-1' analysis of dried fruit can be seen in Figure 6.

If, on the production level, the basic attribute values ('Success of product sales', 'Size of cultivated area on farm', 'Technological equipment of farms' and 'Complexity of processing') change by one degree downwards (− 1), this indicates major bottlenecks of dried fruit on the production level. The analysis shows that the final assessment of dried fruit could improve from *sufficient* to *less successful* or could move in the opposite direction. If, on the marketing level, the basic attribute values

Attribute	I	II	III	IV	V
Final assessment of LFP	Excellent	Sufficient; Less successful	Sufficient	Sufficient; Less successful	Not sufficient
Production	Large	Small; Average	Small	Small; Average	Small
Size of cultivated area on farm	3.1–6.5 ha	3.1–6.5 ha	3.1–6.5 ha	3.1–6.5 ha	3.1–6.5 ha
Number of farms and companies	A lot of	Little	Little	Little	Little
Production	over 350	0–150	0–150	0–150	151–350
Processing	over 350	0–150	0–150	0–150	151–350
Marketing	51–75	0–25	0–25	0–25	0–25
Agriculture resource production	Average	Average	Small	Small	Small
Quantity of source production on farm	Good	Low	Low	Average	Good
Quantity of selling agricultural resources	0–25%	76–100%	0–25%	0–25%	0–25%
Type of agricultural resources	Own	Own	Own	Combined	Combined
Social-economic and environmental impacts	Good	Bad	Bad	Bad	Average
The way of agricultural resource production	6.1–18	0–3	0–3	0–3	6.1–18
Type of farms	Full time	Full time	Full time	Part time	Part time
Technological aspect	Good	Good; Excellent	Good	Good; Excellent	Good
Technological equipment of farms	Good	Average	Good	Excellent	Average
Technological equipment of processing companies	Excellent	*	*	*	*
Complexity of processing process	Complicated	Simple	Not so complicated	Simple	Not so complicated
Processing process	Large	Low	Low	Average	Low
Processing process on farms	76–100 %	76–100 %	0–25 %	76–100 %	51–75 %
Processing process in companies	76–100 %	0–25 %	0–25 %	0–25 %	0–25 %
Final products on farms	Large	Low	Low	Large	Good
Final products in companies	Yes	No	No	No	No
Marketing	Successful	Partially successful	Partially successful	Partially successful	Not successful
Selling a product	Excellent	Excellent	Good	Excellent	Good
Designation	PDO or PGI	No designation	No designation	Own designation	Own designation
Success of product sales	> 95%	> 95%	61–95 %	> 95%	61–95 %
Price	1–20%	< 1%	1–20%	1–20%	1–20%
Organization of marketing	Good	Good	Good	Bad	Bad
Farmers	Yes	Yes	Yes	Yes	Yes
Local public institutions	Yes	Yes	No	No	No
Another way of marketing	No	No	Yes	No	No
Customers	Large	Not sufficient	Sufficient	Large	Sufficient
Local/regional consumers	Yes	Yes	Yes	Yes	Yes
Tourists	Yes	No	Yes	Yes	Yes
Chain of sales companies	Yes	No	No	Yes	No
Other target groups of consumers	No	No	No	No	No

Figure 4. Results of the DEX-i evaluation of local mountain food products I–V.

Attribute	VI	VII	VIII	IX	X
Final assessment of LFP	Sufficient	Excellent	Less successful	Sufficient	Sufficient
Production	Average	Large	Small	Small	Average
Size of cultivated area on farm	3.1–6.5 ha	3.1–6.5 ha	1–3 ha	3.1–6.5 ha	3.1–6.5 ha
Number of farms and companies	Little	Average	Little	Little	Little
Production	0–150	151–350	0–150	0–150	over 350
Processing	0–150	0–150	0–150	0–150	over 350
Marketing	0–25	over 75	0–25	0–25	0–25
Agriculture resource production	Large	Large	Small	Small; Average	Small; Average
Quantity of source production on farm	Large	Good	Low	*	*
Quantity of selling agricultural resources	26–50%	51–75%	0–25%	0–25%	0–25%
Type of agricultural resources	Own	Own	Own	Combined	Own
Social-economic and environmental impacts	Average	Good	Average	Average	Average
The way of agricultural resource production	3.1–6	over 18	6.1–18	3.1–6	6.1–18
Type of farms	Full time	Full time	Part time	Part time	Part time
Technological aspect	Good	Excellent	Good	Good	Good
Technological equipment of farms	Good	Excellent	Average	Excellent	Average
Technological equipment of processing companies	*	Excellent	Good	*	Good
Complexity of processing process	Not so complicated	Not so complicated	Simple	Complicated	Simple
Processing process	Low	Large	Low; Average	Low	Average
Processing process on farms	76–100 %	76–100 %	0–25 %	76–100 %	26–50 %
Processing process in companies	0–25 %	76–100 %	0–25 %	0–25 %	26–50 %
Final products on farms	Average	Large	*	Average	Low
Final products in companies	No	Yes	Yes	No	Yes
Marketing	Not successful	Successful	Successful	Partially successful	Not successful
Selling a product	Excellent	Excellent	Excellent	Excellent	Excellent
Designation	PDO or PGI	PDO or PGI	No designation	Own designation	No designation
Success of product sales	61–95 %	> 95%	> 95%	> 95%	> 95%
Price	< 1%	< 1%	21–50%	1–20%	< 1%
Organization of marketing	Bad	Excellent	Good	Excellent	Bad
Farmers	Yes	Yes	Yes	Yes	No
Local public institutions	No	Yes	No	Yes	No
Another way of marketing	No	Yes	Yes	Yes	No
Customers	Sufficient	Large	Sufficient	Not sufficient	Average
Local/regional consumers	Yes	Yes	Yes	Yes	Yes
Tourists	Yes	Yes	Yes	No	No
Chain of sales companies	No	Yes	No	No	Yes
Other target groups of consumers	No	No	No	No	No

Figure 5. Results of the DEX-i evaluation of local mountain food products VI–X.

Attribute	−1	II	+1
Final assessment of LFP		**Sufficient**; Less successful	
├Size of cultivated area on farm	**Sufficient**	3.1–6.5 ha	
├Production		[**0–150**	
├Processing		[**0–150**	
└Marketing		[**0–25**	
├Quantity of source production on farm		[**Low**	Less successful
├Quantity of selling agricultural resources		***76–100%***	]
└Type of agricultural resources		***Own***	]
├The way of agricultural resource production		[**0–3**	
└Type of farms		***Full time***	]
├Technological equipment of farms	**Sufficient**	Average	
├Technological equipment of processing companies		[*	]
└Complexity of processing process	**Sufficient**	***Simple***	]
├Processing process on farms		***76–100 %***	]
├Processing process in companies		[**0–25 %**	Less successful
├Final products on farms		[**Low**	
└Final products in companies		[**No**	Less successful
├Designation		[**No designation**	
└Success of product sales	**Not sufficient; Sufficient**	***> 95%***	]
├Price		[**< 1%**	
├Farmers		[***Yes***	**Not sufficient; Sufficient**
├Local public institutions		[***Yes***	**Not sufficient; Sufficient**
└Another way of marketing		**No**	]
├Local/regional consumers		[***Yes***	
├Tourists		**No**	]
├Chain of sales companies		**No**	]
└Other target groups of consumers		**No**	]

Figure 6. 'PS-1' analysis of local mountain food product II.

Table 4. Definition of weight values in the first and second scenarios.

	Scenario 1	Scenario 2
	Production	
Weight value (%)—model development	49	49
	Marketing	
Weight value (%)—model development	51	51
	Production	
Weight value (%)—sensitivity analysis	74	29
	Marketing	
Weight value (%)—sensitivity analysis	26	71

Table 5. Final results of the DEX evaluation of the first and second scenarios.

Name of food products	Previous assessments	New assessments (Scenario 1)	New assessments (Scenario 2)
Bovški cheese	*Sufficient*	*Less successful*	*Not sufficient*
Pohorje pot	*Less successful*	*Sufficient*	*Less successful*
Jetrnica	*Sufficient*	*Less successful*	*Not sufficient*

of marketing organization ('Farmers' and 'Local public institutions') change by one degree downwards, this indicates major bottlenecks in the marketing system. Other attributes of production and marketing do not have any impact on the final assessment if their values change by one degree upwards or downwards.

Examining the PS-1 analysis results (Fig. 6), we can recognize the main bottlenecks that appear in both the production and marketing processes: (a) the number of mountain farms included in any kind of association for the production, processing or sale of LFP is low; (b) there is a lack of sufficient cultivated land and food resources; and (c) a small quantity of final products are offered on farms and local shops. All stated bottlenecks supplement one another and are closely linked. The reasons for the stated bottlenecks are hidden in historical and political backgrounds, the general development situation in the Slovenian mountains and environmental conditions. We also note that if the networking between various actors in the production and/or marketing processes is more powerful, the products appear more strongly in the market, even if there are not high quantities of the final products (Zgornjesavinjski zelodec). For example, cider is perceived as unsuccessful (the final assessment is *not sufficient*). Although a large number (more than 700) of producers are present in the region, they are not organized at all. The second interesting example is the Pohorje pot (made from local vegetables, herbs, fungi and meat ingredients). There are only 18 producers of the final product, but the product is well-known because of successful networking between public and private actors and marketing in the region. The biggest producer is the private company Unitur-Rogla, which markets the pot for local hotels, spas and restaurants. Other smaller producers market the pot during festivals, on holiday farms and in restaurants.

Sensitivity test of the model

A sensitivity test is used to establish the responsiveness, efficiency and applicability of the developed model. The test, based on a simulation of scenarios with changing weight values, is reported in Table 4. Some authors[35] suggest a simulation approach for a high-dimensional-sensitivity analysis of the weights of multi-criteria decision models. In the first scenario (simulation), the weight values were higher for 'Production' and lower for 'Marketing' (74%:26%). In the second scenario (simulation), the weight values for production were 29% for 'Production' and 71% for 'Marketing'.

With the changing weight values of production and/or marketing in Scenarios 1 and 2, we attempted to examine how this could influence the final assessment of LFP. The results of the test show that the final assessments were changed by one degree downwards or upwards for three LFP (Table 5). For the first scenario, the assessment of Bovški cheese changed from *sufficient* to *less successful*, that of Pohorje pot changed from *less successful* to *sufficient* and that of Jetrnica changed from *sufficient* to *less successful*. The similar changes could be recognized for the second scenario. For all other food products, the final assessment did not change.

The various outputs of Scenarios 1 and 2 for Bovški cheese, Pohorje pot and Jetrnica depend on the different input data, as well as on the weight values. For example, in the cases of Bovški cheese and Jetrnica, the final results of Scenario 2 show a deficiency in the marketing system as compared to Pohorje pot. The opposite results could suggest a deficiency of the production system for Pohorje pot. The results obtained in this sub-section give a clear insight into what main attribute must be changed/improved or further developed to facilitate the successful promotion of local food products.

The results of the sensitivity test show that DEX methodology is suitable for the assessment of the production and marketing systems for local mountain food. With relatively simple usage and good model transparency (hierarchical approach), the DEX method could be recognized as a user-friendly tool. The value of the model also lies in the possibility of upgrading the model with specific attributes for improving the various segments of food systems.

Conclusions

A study of local food from the Slovenian mountains was performed in order to discover precisely where in the production and marketing system the main bottlenecks, which inhibit the development of the local food concept, exist and whether the DEX method is appropriate for the assessment of the production and marketing of local mountain food. The method was applied to ten selected local mountain food products. The multi-criteria DEX model allows for: (i) the critical assessment of the production and marketing of local mountain food products and (ii) acquiring feedback from food chain actors in order to improve certain phases of production and/or marketing. The model expresses a wide range of practical applicability, but to achieve the final success of LFP and a positive impact on rural development (social, economic and environmental) issues, other factors must be taken into consideration (e.g., the creation of a public–private partnership, horizontal and vertical networking between food chain actors and the willingness and enthusiasm of local individuals)[36].

With the exact definition of bottlenecks (attributes), we can also demonstrate how a change in a given attribute (an increase or decrease of attribute values) will affect the final assessment of local food products. This allows us to advise actors along the food chain about how to react and which phase should receive the most attention. Because of its relatively simple usage, the model is suitable for a wide range of users along the food chain, but in particular, it could be applied to local policy decision-makers and extension services. The determination of bottlenecks in the production and marketing processes of all the examined local mountain food products was quite surprising because they arise mostly from historical, political, social and environmental issues. To consider the situation from a different perspective, all stated bottlenecks could also be discussed as opportunities because there still is a great deal of room in the market for quality mountain products, especially in the tourism branch and more extended markets, e.g., regional or national ones. The bottlenecks can also be partially overcome by more-organized production, networking in the food chain, public–private partnerships and more-professional work.

References

1 Pacciani, A., Belletti, G., Marescotti, A., and Scaramuzzi, S. 2001. The role of typical products in fostering rural development and the effects of regulation (EEC) 2081/92. In 73rd Seminar of the European Association of Agricultural Economists. Ancona, Italy.

2 Hingley, M., Boone, J., and Haley, S. 2010. Local food marketing as a development opportunity for small UK agri-food business. International Journal of Food System Dynamics 3:194–203.

3 Vecchio, R. 2010. Local food at Italian farmers' Markets: Three case studies. International Journal of Sociology of Agriculture and Food 17(2):122–139.

4 Tregear, A., Arfini, F., Belletti, G., and Marescotti, A. 2007. Regional foods and rural development: The role of product qualification. Journal of Rural Studies 23(1):12–22.

5 Bessiere, J. 1998. Local development and heritage: Traditional food and cuisine as tourist attractions in rural areas. Sociologia Ruralis 38(1):212–34.

6 Weatherell, C., Tregear, A., and Allinson, J. 2003. In search of the concerned consumers: UK public perceptions of food, farming and buying local. Journal of Rural Studies 19:233–244.

7 EuroMARC, 2010. Smernice za razvoj, promocijo in komuniciranje o gorsko-hribovskih prehranskih izdelkih: Guidelines for stakeholders of the mountain food supply chains and related sectors. Available at Web site http://www.euromontana.org/images/stories/projets/EuroMARC/docs_NL_et_actes/guidelines_euromarc_report_sl.pdf (verified April 5, 2011).
8 Barjolle, D., Paus, M., and Perret, A. 2009. Impacts of geographical indications review of methods and empirical evidences. In Paper Presented at the IAAE Conference. Beijing, China.
9 Marescotti, A. 2003. Typical products and rural development: Who benefits from PDO/PGI recognition? In 83rd EAAE Seminar (Food Quality products in the advent of the 21st Century: Production, Demand and Public Policy), Chania, Greece.
10 Ilbery, B. and Kneafsey, M. 2000. Producer constructions of quality in regional speciality food production: A case study from South West England. Journal of Rural Studies 16:217–230.
11 Bratec, M. 2007. Slovenian gastronomy: Through issues of quality or communication, Assignment for the course of Strategic Communication, University of Southern Denmark, Odense, Denmark.
12 Bratec, M. 2008. Aiming towards sustainable (tourism) development: The case of the slow food movement and its impacts in Slovenia. Assignment for the Course of Sustainable Tourism Development, University of Southern Denmark, Odense, Denmark.
13 Majkovič, D. and Borec, A. 2010. Are consumers in Slovenia concerned about the mountain quality food? Journal for Geography 5(1):115–124.
14 Rozman, Č., Pažek, K., Bavec, M., Bavec, F., Turk, J., and Majkovič, D. 2006. The multi-attribute analysis of spelt food processing alternatives on small organic farms. Journal of Sustainable Agriculture 28(2):159–179.
15 Tiwari, D.N., Loof, R., and Paudyal, G.N. 1999. Environmental-economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques. Agricultural Systems 60:99–112.
16 Saaty, T.L. 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.
17 Pažek, K., Rozman, Č., Bavec, F., Borec, A., and Bavec, M. 2010. A multi-criteria decision analysis framework tool for the selection of farm business models on organic mountain farms. Journal of Sustainable Agriculture 34(7):778–799.
18 Bohanec, M. and Rajkovič, V. 1990. DEX: An Expert System Shell for Decision Support. Sistemica 1(1):145–157.
19 Parra-Lopez, C., Calatrava-Requena, J., and De-Haro-Gimenez, T. 2008. A systemic comparative assessment of the multifunctional performance of alternative olive systems in Spain within an AHP-extended framework. Ecological Economics 64(4):820–834.
20 Alphonce, C.B. 1997. Application of the analytic hierarchy process in agriculture in developing countries. Agricultural Systems 53(1):97–112.
21 Galli, F., Carbone, A., Caswell, J.A., and Sorrentino, A. 2011. A multi-criteria approach to assessing PDOs/PGIs: An Italian pilot study. International Journal of Food System Dynamics 2(3):219–236.
22 Tojnko, S., Rozman, Č., Unuk, T., Pažek, K. and Pamič, S. 2011. A qualitative multi-attribute model for the multifunctional assessment of 'Streuobst Stands' in NE Slovenia. Erwerbs-Obstbau 53(4):157–166.
23 Bohanec, M. 2008. DEXi: Program for Multi-attribute Decision Making. User's Manual, Version 3.00. IJS Report DP-9989. Jozef Stefan Institute, Ljubljana. Available at Web site http://kt.ijs.si/MarkoBohanec/pub/DEXiManual30r.pdf (verified March 15, 2011).
24 Pelzer, E., Fortino, G., Bockstaller, C., Angevin, F., Lamine C., Moonen, C., Vasileiadis, V., Guérin, D., Guichard, L., Reau, R., and Messéan, A. 2012. Assessing innovative cropping systems with DEXiPM, a qualitative multi-criteria assessment tool derived from DEXi. Available at Web site http://www.oecd.org/std/clits/42495745.pdf (accessed September 30, 2012).
25 OECD, European Commission, Joint Research Centre. 2008. In M. Nardo, M. Saisana, A. Saltelli, S. Tarantola (EC/JRC), A. Hoffman, and E. Giovannini (OECD) (eds). Handbook on Constructing Composite Indicators: Methodology and User Guide. OECD Publication Code: 3020008251E1. p. 1–160.
26 Rozman, Č., Potočnik, M., Pažek, K., Borec, A., Majkovič D., and Bohanec, M. 2009. A multi-criteria assessment of tourist farm service quality. Tourism Management 30:629–637.
27 Hyde, K.M. and Maier, H.R. 2006. Distance-based and stochastic uncertainty analysis for multi-criteria decision analysis in Excel using Visual Basic for Applications. Environmental Modelling and Software 21:1695–1710.
28 Rozman, Č. and Pažek, K. 2005. Application of computer supported multi-criteria decision models in agriculture. Agriculturae Conspectus Scientificus 70(4):127–134.
29 Pažek, K., Rozman, Č., and Borec, A. 2007. The application of simulation and multi-criteria decision models to support decision making on farms with agricultural production in less favoured areas. Faculty of Agriculture and Life Sciences, University of Maribor, Maribor, Slovenia.
30 Pavlovič, M., Cerenak, A., Pavlovič, V., Rozman, Č., and Bohanec, M. 2011. Development of DEX-HOP multi-attribute decision model for preliminary hop hybrids assessment. Computers and Electronics in Agriculture 75:181–189.
31 Hermann, B.G., Kroeze, C., and Jawjit, W. 2007. Assessing environmental performance by combining life cycle assessment, multi-criteria analysis and environmental performance indicators. Journal of Clenear Production 15:1787–1796.
32 Bohanec, M., Zupan, B., and Rajkovič, V. 2000. Applications of qualitative multi-attribute decision models in health care. International Journal of Medical Informatics 58–59:191–205.
33 Prišenk, J. 2012. Development of multi-criteria model for assessment of food products from mountain areas. Masters thesis, University of Maribor, Faculty of Agriculture and Life Sciences.
34 Belton, V. and Stewart, J.T. 2002. Multiple criteria decision analysis. An integrated approach. Kluwer Academic Publishers, Massachusetts.
35 Butler, J., Jia, J., and Dyer, J. 1997. Simulation techniques for the sensitivity analysis of multi-criteria decision models. European Journal of Operational Research 103:531–546.
36 Murdoch, J., Marsden, T., and Banks, J. 2000. Quality, nature and embeddedness: Some theoretical considerations in the context of the food sector. Economic Geography 76(2):107–125.

Renewable Agriculture and Food Systems: 29(4); 355–365 doi:10.1017/S1742170513000239

Economic analysis of private and public benefits of corn, switchgrass and mixed grass systems in Eastern South Dakota

Nelly Bourlion[1], Larry Janssen[2]* and Michael Miller[2]

[1]Global Environment Facility – World Bank, Washington DC, USA.
[2]Department of Economics, South Dakota State University, Brookings, SD, USA.
*Corresponding author: Larry.Janssen@sdstate.edu

Accepted 8 May 2013; First published online 19 July 2013 **Research Paper**

Abstract

The objective of this research is to develop an economic analysis of different crop mix biofuels programs for meeting ethanol and sustainability demands. Primary data are from South Dakota State University field experiments on farms located in east-central South Dakota. The data include 4 years of field data, three crop systems (mixed grass, switchgrass and corn), two residue treatments (no removal, removal of biomass), and three landscape positions (back slope, crest and foot slope). A representative farm model and five scenarios are developed to conduct a full budget analysis over a 12-year period. Public benefits are evaluated, using the benefit transfer method to value ecosystem services, by allocating a dollar value to three environmental variables; carbon sequestration, reduction of sedimentation and pheasant production. Stochastic simulation results are compared for each of the five scenarios, one with only annualized net private returns, and one including the value of environmental benefits. Results indicate that: (1) the conventional continuous corn scenario has the highest net returns over the 12-year budget, (2) carbon sequestration represents 80% of the environmental benefits, and (3) the added economic value of ecosystem services does not provide enough incentives for farmers to convert from corn production to grass production.

Key words: biofuels, switchgrass, crop budgets, environmental benefits, South Dakota

Introduction

Energy production from biofuels feedstock is often viewed as a potential approach to reduce reliance on oil, stabilize energy prices, mitigate climate change and improve rural economic development[1–3]. Controversies about how sustainable corn-based ethanol can be used to replace fossil fuels include the large amount of arable lands required for the crops, the impact on grain supply, the land use change effects, the carbon emission balance, the subsidies, and the protective trade measures that were provided to the ethanol industry for many years. While additional acreage for the production of biofuels feedstock can be found from utilizing previously uncropped lands and by converting production from the growing of other crops, corn grain-based ethanol development will still be limited by land availability[4,5]. Devoting all US corn and soybean acreage to ethanol and biodiesel production would offset only 12 and 6%, respectively, of gasoline and diesel consumption for transportation fuel[6]. The Northern Plains region, one of the major corn growing areas of the nation, is expected to experience a shift in crop production from providing food and fiber to an emphasis on energy farming.

Recent attention has been focused on second-generation biofuels from cellulosic feedstock, such as perennial grasses and crop residues. However, the increase in corn stover supply is associated with reductions in soil organic carbon, increases in nitrogen application and increases in corn prices[7]. Switchgrass is identified as a promising crop because of its high yield compared with other perennial grasses, its efficiency in using nutrients, and its growing conditions and equipment use are similar to those for corn[8]. Cellulosic grasses for biofuels production play an important role for the environment in controlling nutrient loss, reducing erosion, maintaining soil carbon level, extending habitat for wildlife, reducing input requirements and so forth[5]. However, perennial grasses that would produce cellulosic ethanol are not yet grown on a commercial scale.

The overall objective of this research is to develop an economic analysis of different crop mixing biofuels

© Cambridge University Press 2013

programs to meet ethanol and sustainability demands. This analysis is separated into two parts: the private profitability and the environmental benefits. The specific objectives of this paper are to (1) identify which systems (mixed grass, switchgrass and corn) on which landscape positions are the most profitable for farmers; (2) determine the variability of net-returns depending on the expected yields and prices; and (3) evaluate the environmental benefits of these practices.

This study is part of a research project conducted at South Dakota State University. The paper intends to establish which system provides sufficient economic incentives for farmers in response to the increasing demand for ethanol. Because profitability is one of the main goals of farmers, farmers will produce cellulosic feedstock only if the expected economic return from including it in their production system is equivalent or higher than the returns from the most profitable conventional crops.

Literature Review

The Energy Independence and Security Act (EISA), signed into law in 2007, is the most important legislation concerning biofuels production[1]. EISA requires a minimum of 15 billion gallons of corn-based ethanol by 2015 and the use of 21 billion gallons of advanced biofuels by 2022.

Profitability of ethanol production for farmers

Biofuels production is planned to drastically increase over the next several years and to significantly impact the commodity markets[9,10]. Corn has been the preferred source of ethanol feedstock in the USA since the Energy Policy Act of 1978 provided a 40-cent tax exemption per gallon of ethanol to blenders of gasoline and ethanol[11]. Since that time, the corn-based ethanol industry has successfully fought for a variety of subsidies, tariffs and mandates that support corn's use as the predominant ethanol feedsource[12]. However, the use of corn as the main input for ethanol production raises concerns about the negative environmental impacts associated with its production. An alternative to this production is cellulosic ethanol which relies on non-food feedstock; crop residues or perennial grasses. The economic potential of cellulosic crops depends on yields, cost of production, input requirements, technology and also on energy market substitutes such as natural gas.

Khanna estimated the breakeven total costs of switchgrass to be between US$277.8 and 264.2 per metric ton of dry matter, while it was between US$111.3 and 93.1 per metric ton of dry matter for corn stover[13]. Mooney et al. completed a study focused on management practices and production costs of switchgrass varying across different production environments[14]. The authors found that switchgrass production costs range from US$49 per metric ton in the well-drained level upland environment to US$77 per metric ton in the marginal environment poorly drained flood plain. Another study completed by Bangsund et al. in south-central North Dakota generated costs of producing switchgrass over a range of soil productivity and farm profitability scenarios[15]. Production costs were US$44 per metric ton on marginal soil and US $38 per metric ton on highly productive soil. They found that the opportunity cost from not producing traditional crops on the same acreage is the major economic criterion influencing the switchgrass breakeven price.

Given the high initial investment and the multi-year production process, market risk is a crucial subject to understand farmers' willingness to adopt bioenergy crops. Farmers face two main sources of uncertainty; production and prices. Major cellulosic energy crops are perennial and need several years to reach their maximum yield potential. Therefore, it represents a long-term commitment and investment for farmers. Song et al. found that if the land is currently in a corn–soybean rotation, the minimum switchgrass return from converting the land to switchgrass should be between US$259 and US$778 ha^{-1} depending on the risk assumptions[16].

Environmental, social and economic welfare of biofuels production

These new crop mixing systems have been introduced in the EISA legislation for the purpose of improving sustainability and protecting the environment[1]. Biofuels not only provide a renewable source of energy, but also have the potential to produce a wide range of environmental benefits; fertilizer and chemical input requirements are fairly low relative to conventional crops, switchgrass provides better habitat for wildlife, native mixed prairie grass enhances biodiversity in the landscape, and so forth[13,17].

The major limitation of studying ecosystem services is the method used to attach a dollar value to these services. The method most often used is the benefit transfer method that 'estimates economic values by transferring existing benefit estimates from studies already completed for another location or issue'[18]. Babcock et al. provide estimates of the costs associated with inducing conversion of land from traditional crops to switchgrass[19]. They also examine the potential environmental consequences of conversion and studied three land-use scenarios. The first scenario, entirely switchgrass, is predicted to reduce sediment by 84%. The second scenario, continuous corn, is predicted to increase sediment yield by 23%. The third scenario, a combination of switchgrass and continuous corn, gives mixed results with a reduction in sediments of 19%. This study is very useful for quantifying the effects of growing switchgrass compared with corn on sedimentation; however, it does not monetize these changes.

A study published by Gascoigne et al. (p. 1715) 'uses biophysical values derived for the Prairie Pothole Region of North and South Dakota, in conjunction with value transfer methods, to assess environmental and economic

tradeoffs under different policy relevant land use scenarios over a 20 year period'[20]. The authors valued and compared three indicators; carbon sequestration, reduction in sedimentation and waterfowl production, across four land-use scenarios, each involving different combinations of Conservation Reserve Program (CRP), native prairie and cropland hectares. They identified the ecosystems services by land use, quantified them with a biological value, and monetized these values using benefit transfer methods. Finally, the authors standardized these values to a per-hectare basis to compare them with other land incomes. The method developed by Gascoigne et al. is used in this paper[20]. Gascoigne et al. found that the aggressive conservation scenario, in which all remaining native prairie in the study area is preserved and there is a 50% increase in CRP/Wetland Reserve Program (WRP) lands in the region that are substituted away from overall cropland, increases all ecological measures. When native prairie loss is minimized and CRP lands increased, the societal benefits are the highest. All other scenarios reduced all ecological measures modeled. The scenario converting the native prairie land into cropland results in a social welfare loss of more than US$4 billion.

Concerns about energy security and environmental sustainability are creating interest in new practices, such as second-generation biofuels, and legislation that help reach independence from fuel imports and protects the environment. Greater emphasis on perennial grasses in cropping systems could lead to changes in environmental, social and economic welfare. Several studies have shown environmental improvements of this renewable energy source on greenhouse gas emissions, soil erosion and so forth[1,4,13]. However, none of these studies are focused on farm-level analysis, which is the main focus of this study.

Research Design

Main sources of data

Primary data for this research come from South Dakota State University field experiments on farms located in east-central South Dakota[21]. It is part of a larger project called Eco Sun Prairie farm. This information includes 4 years of field data from 2008 to 2011. Each year contains data collected from three cropping systems (mixed grass, switchgrass and corn), with each system subject to two residue treatments (no removal, and excess removal of biomass), and three landscape positions (back slope, crest and foot slope). To facilitate the analysis, each rotation is split depending on its landscape position and residue treatment. The field experiments include two sites; Colman (no-till system) and Flandreau (conventional tillage). There is no mixed grass in Flandreau. Each of the 30 combinations is analyzed in a full capital budget.

Farming practices on these lands are similar to local farming practices. Biomass and grain yields are measured; erosion potential is estimated; nitrogen, phosphate and potassium distribution within the landscape is determined as well as basic soil quality (aggregate stability, soil texture, bulk density and organic carbon distribution).

Conceptual model: methods of analysis for private benefits

A full capital budget analysis is developed for each of the 30 management options to determine the breakeven price and the profitability of each system at the simulation farm level. It is focused not only on net returns, but also on gross returns, total direct costs and total costs. Cellulosic feedstock are perennial crops and, according to experts, a normal switchgrass and mixed grass stand can be harvested and produce to their full potential for up to 10–15 years. Therefore, the capital budget is based on price, cost and management scenarios for a 12-year period, and includes the annualized costs of establishing switchgrass and mixed grass.

A continuous corn rotation is introduced in the analysis as comparison. Several types of data are needed to develop the budget analysis: yields, hectares, input prices, output prices, government payments, crop insurance, machinery costs, land charge and drying costs.

The bioenergy farm model. Because these data need to be applied to a commercial scale farm model for analysis, a 404.7 ha (1000 acres) energy farm model is developed for nine counties in east-central and southeast South Dakota (Brookings, Clay, Lake, Lincoln, McCook, Minnehaha, Moody, Turner and Union)[22]. This model is standardized for natural resource, land use, policy program and management characteristics[23].

Different scenarios based on soil properties and yields. Five different scenarios are established based on the yields of the experimental fields and on the soil properties described by Web Soil Survey (Table 1). The results of profitability and net returns are generalized to each scenario for the farm model.

Budget generalization to a 12-year period. Switchgrass and mixed grass are perennial grasses and are not harvested during the first year of implementation; therefore, the budgets are generalized over a 12-year period. The method used is the net present value of a stream of net benefits (B_0,..., B_{11}) received over a period of 12 years:

$$\text{PV}\,[B_0, \ldots, B_{11}] = \sum_0^{11} Bi/(1+0.03)^i.$$

A 3% discount rate is used, as this is the central rate presented in the US government assessment[24]. Compared to recent literature, our data show that the first 3 years of grass yields recorded are very low compared to what a farmer should expect. The fourth year of grass yields from the experimental plots is closer to yield estimates in the literature, around 9 metric tons ha^{-1}[13,14,20]. Therefore, the net return of the fourth year is used as if each year a farmer could generate this net return. The net return is then discounted at a 3% rate. For corn, from the first year

Table 1. Description and justification of the five scenarios.

Scenario	Corn (%)	Switchgrass	Mixed grass (%)	Landscape position	Justification
1	100	0	0	Not considered	
2	0	50	50	Not considered	Ensure the diversity of revenues and limit the risks
3	80	10	10	Not considered	Agricultural land use average grass yield of 9 metric tons ha^{-1} necessary
4	50	25	25	Not considered	Crop productivity index, corn grown on soils with index >80
5	25	37.5	37.5	Corn on slope <2% grass on slope >2%	

Table 2. Annual average crop prices for South Dakota. Source: NASS.

	2008	2009	2010	2011
Corn for grain (US$ per metric ton)	148.8	127.2	200.8	238.2
Grass 1. Hay other w/o alfalfa (US$ per metric ton)	86.0	77.2	76.1	100.3
Grass 2. All hay (US$ per metric ton)	102.5	88.2	85.4	130.1

of our data record, the yields correspond to the average yield estimated in the literature. Therefore, the average annual net returns for the first 4 years of data is calculated and then this average is considered as the net return a farmer could get every subsequent year. This is also discounted at a 3% rate. This method allows for making the comparison between budgets and scenarios without trying to project any future prices or yields that are uncertain, especially for switchgrass and mixed grass.

Input prices. Input prices are determined based on the management schedules given by the researchers of the EcoSun Prairie farm experimental fields[23]. Seed prices for corn, as well as fertilizer and herbicides prices, are established using data from the National Agricultural Statistics Service (NASS) and the South Dakota Agriculture bulletins for 2008, 2009, 2010 and 2011. Seed prices for switchgrass and mixed grass are determined from interviews with experts from Millborn Seed and data generated from the experimental fields. In this model, only corn is considered to be a farm program crop eligible for farm program subsidy payments and crop insurance. Machinery costs and corn drying costs are estimated using the Iowa Custom Rate of the appropriate years[25]. Land charge is established with the average cash rental rates of the nine counties in the study area found through the South Dakota Agricultural Land Market Trends[26].

Output prices. South Dakota annual average corn prices are used, and are collected from the NASS website[27]. Perennial grass production is not yet well-established; therefore, prices are difficult to find. Two price scenarios are considered; the first one is based on 'all hay' prices and the second one based on the 'other hay (non-alfalfa hay)' prices, both specific to the state of South Dakota. Experts at Millborn Seed were also interviewed and confirmed the price range (Table 2).

Conceptual model: methods of analysis for public benefits

Another study was conducted to estimate the public benefits of the bioenergy crops systems. To do so, a dollar value was allocated to environmental variables that impact sustainability and welfare. The valuation method uses biophysical values from the experimental fields of Eco Sun Prairie Farm, as well as value transfer methods to assess environmental tradeoffs under different land-use scenarios. The valuation method is composed of three essential steps: (1) identify ecosystem services by land use; (2) quantify the biological values associated with those services and annualize them to a per hectare value; and (3) monetize those values using economic methods. By standardizing measurement to a per hectare value, ecosystem services can be compared with other land incomes.

In this paper, the benefit transfer method is used to monetize three non-market ecosystem services; carbon sequestration, reduction of sedimentation and pheasant production. The data for the first two services come from the EcoSun Prairie farm experiment, and the pheasant production data come from the South Dakota Department of Game, Fish and Parks[28]. Previous research completed in other regions in the Northern Plains shows that these three services are the most valuable in our study area[20]. These three ecosystem services are analyzed and valued for two specific land covers; switchgrass and mixed grass scenarios are compared with a conventional continuous corn system. Results from each ecosystem service are generalized to the simulation farm and five different scenarios. It should be noted that this study measures only the individual contributions of the indicators and makes no attempt to combine the indicators in any fashion. In particular, the ability to capture and sequester carbon may be significantly reduced when soil is lost through erosion and, thus, lead to greater environmental damage and long-term profit losses than are derived in this work.

Carbon sequestration data. Soil organic matter is estimated separately for upland and wetland zones. For each zone, data are collected for summit, shoulder, upper back slope, lower back slope and foot slope positions[29]. To estimate potential carbon gains or losses from changing land cover, soil organic matter data are converted into soil organic carbon using a conversion factor of 1.724[30]. Then soil organic carbon is converted to a per hectare basis following the equation: $C\ (Mg\ ha^{-1}) = C\ (g\ kg^{-1})\ de \times 10^{-2}$, where $d = 1.30\ g\ cm^{-3}$ and $e = 15\ cm$ are the bulk density and thickness, respectively, representative for agricultural surface soil (EcoSun Prairie farm experts). To calculate the carbon sequestration change of converting cropland to grasslands, the sequestration potential of cropland is found in the literature. The value used is 4% by weight[31]. This means that in 1 kg of soil there are 40 g of soil organic matter. This value was confirmed by Douglas Malo, professor in soil sciences Department at South Dakota State University. The mean estimate for cropland is then subtracted from those of grassland to arrive at the potential net gain from conversion of cropland to grassland. The soil data of the EcoSun Prairie farm are collected 4 years after the conversion of cropland to grasslands. Therefore, the net differences in mean estimates between cropland and grassland are divided by four to find the sequestration rate of Soil Organic Carbon. Once carbon flux has been determined, it is converted into units of carbon dioxide equivalents (CO_2e) by multiplying by the conversion factor of 3.67.

The annualized carbon sequestration output can be converted to a dollar value by using estimates of the social cost of carbon, carbon market prices or estimates of the cost of carbon capture and storage[32]. In 2009, a US government interagency working group calculated the social cost of carbon estimates to be used in regulatory impact analysis[24]. The four social costs of carbon estimates chosen by the group were US$5 per ton of CO_2e, US$21per ton of CO_2e, US$35 per ton of CO_2e and US$65 per ton of CO_2e (2007, US$). The first three estimates are based on the average social costs of carbon across models and socio-economic and emissions scenarios at the 5, 3 and 2.5% discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the social costs of carbon distribution. For more information on these estimates see the technical support document realized by the US Working Group under Executive Order 12866[24].

The amount of CO_2 sequestered/emitted is multiplied by the social cost of carbon price for each year. The monetary values are discounted back to the present with a 3% real discount rate. Since the first part on private profitability is calculated on a 12-year scale, the timeline applied here is 12 years using the formula of the present value of a stream of net benefit ($B_0, \ldots, B_{11}$) received over a period of 12 years: $PV\ [B_0, \ldots, B_{11}] = \sum_0^{11} Bi/(1+0.03)^i$.

Reduction of sedimentation. Numerical data on erosion estimates are based on tillage erosion and water erosion models for specific management systems, the main causes of erosion on the farm, and the climate from the county. Sedimentation is more difficult to estimate as most of the eroded soil is translocated and deposited in the fields. However, the typical range for a sediment delivery ratio in agricultural systems is around $25 \pm 15\%$.

Per ton benefit values for reduced soil erosion are derived from Hansen and Ribaudo[33]. This study estimates the economic values that both the public and private sectors place on fluctuations of soil quality. In the study area defined earlier the average value is US$0.455 per metric ton. The total benefit is calculated by multiplying the economic soil loss values by the changes in erosion (from cropland to grassland). These results are summed across the 12-year period and a 3% discount rate is used to calculate the net present value.

Pheasant habitat sustainability. The experimental fields at the EcoSun Prairie farm did not allow for the collection of unbiased information on wildlife in the area as the medium-sized plots under study were insufficient in size to provide the necessary habitat for some species and necessitated the use of benefit transfer methodology. For this benefit transfer estimate, the value of one pheasant of US$57.15 is found by dividing the total expenditures by the total number of pheasant harvested[28]. The average number of pheasants present on the fields in the study area is found by dividing the number of pheasants harvested by the number of hectares operated in farms. The number of additional pheasants in a grass field compared with a corn field has not been estimated; therefore, we use data from CRP grass fields. Nielson et al. found an estimated 22% increase in ring-necked pheasant counts for every increase of 318 ha of CRP vegetation[34]. In reality, the relationship between the size increase of CRP fields and the number of pheasants is not linear. However, to simplify this analysis we consider it linear.

Conceptual model: methods of analysis for the simulation of risky scenarios

Capital budgets are important for farmers, but it is also essential to understand the variation in crop rotation preferences under different risk preferences. Variability of prices and yields are major sources of risk in agriculture. In this study, a stochastic dominance and a stochastic efficiency is used to order risky alternatives. Simetar©, a simulation Excel add-in, provides a method for analyzing data and simulating the effects of risk[35]. It is used to stochastically simulate prices and yields of all five scenarios.

Two simulations are realized into Simetar©. The first includes only private profitability, and the second one includes private profitability and environmental variables. Both of the simulations are based on the net returns calculated in the capital budget. This approach allows the

evaluation of the effects of environmental benefits on profitability.

Output prices are simulated using a normal distribution. This requires using the average yearly price and the standard deviation calculated from the monthly prices for each year. The 4 years of corn prices are used, as well as the two different levels of grass prices. Yields of corn and grass from each of the 30 rotations are simulated using an empirical distribution.

In the second simulation, environmental variables are also simulated. Social costs of carbon are simulated using a truncated normal distribution centered on the value of US$21 per ton of CO_2e. The four social costs of carbon estimated by the US government interagency working group are used to calculate the standard deviation. The amount of carbon sequestered is simulated with an empirical distribution using the data found for the different types of land and landscape position. The amount of erosion is simulated with an empirical distribution using the low, high and mean values from the EcoSun Prairie farm data. The value for every additional pheasant is simulated with a normal distribution centered on the price used of US$57.15. The standard deviation is calculated from the price for each different county of the study area. The pheasant number is simulated with an empirical distribution using the data for each county in the study area.

These environmental values and other variables of interest (indemnity payment, gross return, total cost and net return) are entered in the simulation engine of Simetar© and run through 500 iterations for each year, each scenario and each variable. The 6000 samples of net returns from each scenario are compared with each other using stochastic dominance and probability analysis.

Empirical Results and Discussion

Private profitability budgets

The budget analysis is conducted for the years 2008, 2009, 2010 and 2011. Results for returns to management and labor, gross returns and total costs are discussed in the following section. Using these results, the five risky scenarios can be ranked from best to worst. However, the stochastic simulation and the level of risk are not included in this part and are analyzed in a later section.

Returns to management and labor for the 4 years of field experiments. For the first 2 years of data, switchgrass and mixed grass have negative net returns due to low or no yields during the establishment period. For the last 2 years, switchgrass and mixed grass net returns are positive, yields are high enough and costs are low after the years of establishment. Over the entire period, mixed grass seems to have lower net returns than switchgrass, mainly due to lower yields.

The year 2008 has positive net returns for corn, but lower than for the subsequent years and the yields were high but the price was low. In 2009, the net returns were negative. This is due to the extremely high drying costs and low yields. As a result of high corn prices in the final 2 years, net returns increase to their highest values. For the overall period, corn has much higher net returns per acre than either grass.

Switchgrass and mixed grass are reputed to have high yields and are well adapted on marginal lands. Numerous studies have expectations on replacing corn on these lands by switchgrass or mixed grass. However, the 4 years of field plot data do not allow us to confirm these expectations. For the rest of the study the average yield for all positions is used.

Net returns, total costs and gross returns for the simulation farm. The previous per acre results are generalized to a 404.7 ha (1000 acre) simulation farm and to a 12-year budget to take into consideration the year of establishment needed for switchgrass and mixed grass. Five scenarios are compared for gross returns, net returns and total costs (Table 3).

Gross returns are the highest for scenario 1, followed by scenario 3, scenario 4, scenario 5, and finally scenario 2. Overall, this pattern exists for net returns and costs as well, with the rotation with the larger amount of corn ranking the highest. For the 12-year period, the scenario with continuous corn has a cumulative net return of US$2,336,240, while the scenario with only switchgrass and mixed grass has a net return of US$317,500 or US$941,320 depending on the grass price level considered. Corn is highly profitable especially in the first years when switchgrass and mixed grass are being established and production output is low. However, direct costs per acre for corn are much higher than establishment costs and harvesting costs for switchgrass and mixed grass.

Environmental benefits results

Environmental benefits on a per hectare basis. The biophysical results for ecosystem services increase with the amount of grass considered in each scenario. For each ecosystem service, soil organic carbon sequestration, soil erosion and pheasant production, the total stock values for the 12-year period are calculated, as well as the annual flow.

The net present value of soil organic carbon varies across landscape positions and, of course, across the social cost of carbon chosen. The parameters used are therefore very important because these values are extremely variable; from US$7.8 ha^{-1} yr^{-1} in the uplands back slope positions with the social costs of carbon of US$5 per ton of CO_2e to US$303.5 ha^{-1} yr^{-1} in the uplands foot slope with the social costs of carbon of US$65 CO_2e. These estimates could be potentially very important for a decision maker to choose between grass and corn production.

The soil erosion net present values are much lower than for soil organic carbon. Over a 12-year period, soil erosion

Table 3. Net present value of the simulation farm production over a 12-year period for the five scenarios and the two grass price levels (thousands US$).

	Hectares			Grass price level 1 (in thousand US$)			Grass price level 2 (in thousand US$)		
	Corn	SWG	MXG	Gross returns	Total costs	Net returns	Gross returns	Total costs	Net returns
Scenario 1	404.7	0.0	0.0	8252	5916	2336	8252	5916	2336
Scenario 2	0.0	202.3	202.3	2235	1918	317	2859	1918	941
Scenario 3	323.7	40.5	40.5	7049	5116	1932	7173	5116	2057
Scenario 4	202.3	101.2	101.2	5244	3917	1326	5556	3917	1638
Scenario 5	101.2	151.8	151.8	3632	2722	910	4075	2722	1352

Grass price level 1: hay other w/o alfalfa (US$ per metric ton) 2008: 86; 2009: 77; 2010: 76; 2011: 100.
Grass price level 2: all hay (US$ per metric ton) 2008: 103; 2009: 88; 2010: 85; 2011: 130.

Table 4. Net present value [NPV US$] of annual flow and total stock by ecosystem services and simulation farm scenarios.

Parameters	
Simulation farm	404.7 ha
Social cost of carbon	US$21 per ton of CO_2e
Erosion value	Mean

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Corn (ha)	404.7	0.0	323.7	202.3	101.2
Grasslands (ha)	0.0	404.7	80.9	202.3	303.5
Annual flow (US$)					
Soil organic carbon, US$	0.00	22,049	4410	11,024	16,536
Erosion, US$	0.00	4951	99	2476	3713
Pheasant, US$	0.00	425	85	213	319
Total, US$	0.00	27,425	5485	13,712	20,569
NPV of total stock (US$) over 12-year period					
Soil organic carbon, US$	0.00	226,056	45,211	113,028	169,542
Erosion, US$	0.00	50,761	10,152	25,381	38,071
Pheasant, US$	0.00	4358	872	2179	3268
Total, US$	0.00	281,175	56,235	140,588	210,882

Values for scenarios 2–5 are calculated considering scenario 1 as the baseline.

on average could bring to a farmer US$125.48 ha^{-1}, while carbon sequestration could bring US$558.50 ha^{-1}. Therefore, in the decision-making process, soil erosion seems less important than carbon sequestration.

Pheasant production can also be a potential factor for a decision maker. By growing more grass, a farmer could potentially attract more pheasants and therefore, have another source of revenue. However, after calculations, this potential revenue is very low. On a 12-year period, from the additional pheasant attracted by grass production, a farmer would only make an additional US$10.80 ha^{-1}. Therefore, for a decision maker, carbon sequestration would be a preferred factor of decision.

Public benefits generalized to the simulation farm. The first scenario used as a reference for comparison considers only corn, and therefore, no additional value from ecosystem services is added. The second scenario, which considers only grass, is the one with the highest additional value from ecosystem services. It would generate overall US$281,175 over the 12-year period, or an annual flow of US$27,425. Nearly 80% of the ecosystem service value is from soil organic carbon (Table 4).

The three other scenarios are a mix of corn and grass. The third scenario would generate an overall value of US$56,235 over the 12-year period, and an annual flow of US$5,485. Soil organic carbon sequestration is once again the ecosystem service with the highest value. The fourth scenario generates an annual flow of US$13,712 and a total stock of US$140,588 over the 12-year period. The fifth scenario generates an annual flow of US$20,569 and a total stock over the 12-year period of US$210,882.

These estimates are largely influenced by the increase in soil organic carbon due to growing grass. Soil organic carbon sequestration generates more than 80% of the total net present value of the environmental services in each scenario. The soil erosion generates 18% of the total stock value while the pheasant production generates only 2%. Obviously, these ratios would be greatly modified if the price of a ton of CO_2e was different. In this analysis

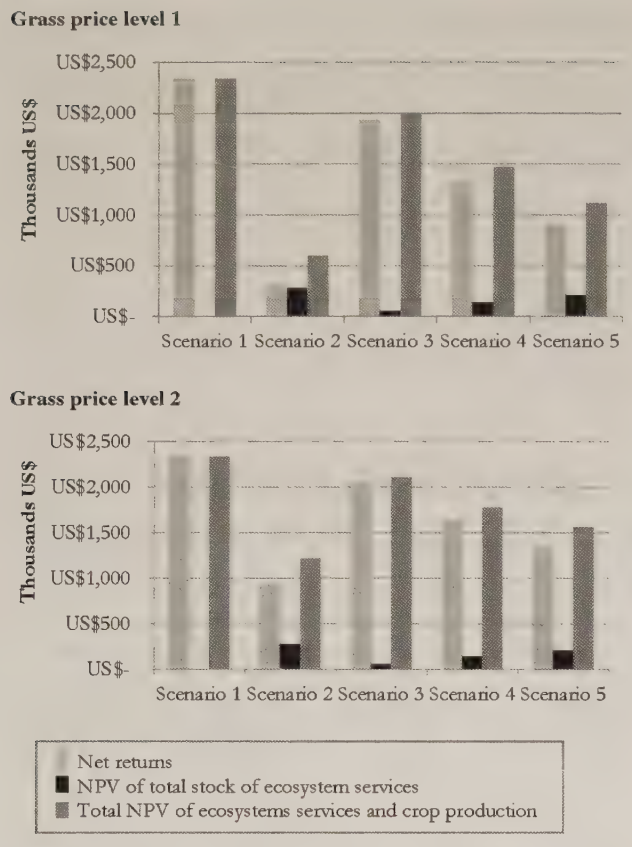


Figure 1. Net present value (thousand $) of the total stock of ecosystem services and of crop production for the simulation farm over a 12-year period, with a social cost of carbon of US$21 per ton of CO_2e.

the social cost of carbon of US$21 per ton of CO_2e is used since it is the central value suggested by the US government interagency group[24]. However, given its considerable dominance in the study, if we look at the lowest price of US$5 per ton of CO_2e, soil organic carbon sequestration has less impact on the overall net present value of total stock. It only represents 49% of the total stock, while soil erosion represents 47%, and pheasant production 4%. This result is also found by Gascoigne et al. who showed that a large investment in native prairie conservation programs would provide a net benefit to society of over US$1 billion over the 20-year policy time period, and that most of these benefits would come from carbon sequestration increases[20]. However, the increase in net benefits to society with the increase of grass proportion remains the same across land use scenarios.

Environmental benefits coupled with private profitability for the simulation farm. When environmental results are coupled with the capital budget analysis, the ranking in scenario based on net returns does not change (Fig. 1). The scenario with only switchgrass and mixed grass is the one with the highest additional value from ecosystem services, generating an increase of US$281,175 over the 12-year period. However, the additional value added by the ecosystem services does not overcome the lost returns

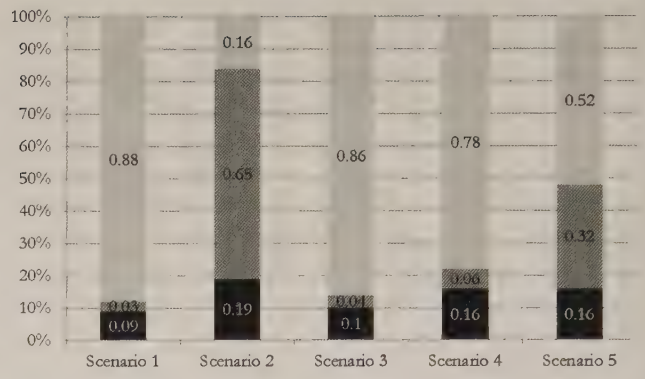


Figure 2. Probabilities of net returns to management and labor < US$0 and > US$100,000 for the simulation farm per year: environmental benefits *are not* included into percentages.

from not growing and selling corn. If the scenarios had to be ranked on the basis of total net returns, scenario 1 would be the highest ranked, even if it does not consider any additional benefits from environmental values. The ecosystem services value is therefore not high enough to influence farmers' decisions to convert their land from corn to grass. Hence, incentives for environmental benefits must be much higher to be competitive with the net returns of crop production.

Stochastic analysis

Stochastic Dominance with Respect to a Function (SDRF) and Stochastic Efficiency with Respect to a Function (SERF) are performed through Simetar©. These analyses evaluate the five scenarios based on alternative risk preferences. SDRF and SERF are performed using 6000 samples for each scenario. The results are presented through probabilities of net return and stochastic efficiency ranking schedule.

StopLight analysis. The StopLight chart, or probabilities of net returns, represents the probabilities of target values. Simetar© calculates and reports the probability of achieving a preferred target (US$100,000) and probability of failing to achieve a minimum target (US$0). A value of $100,000 is chosen to represent an overall net return of US$247 ha^{-1} yr^{-1} (US$100/acre yr^{-1}), and US$0 is chosen as the lower target to represent the probability of loss.

Without the environmental benefits included in the analysis, scenario 1 and scenario 3 have the lowest probability of losses with 9 and 10%, respectively (Fig. 2). The worst performing scenario is scenario 2 with 19% probability of losses. The more grass is grown in the scenario the worse is the probability of positive net returns. Scenario 2, which considers grass only, has a probability of net returns higher than US$100,000 per year of 16% while the scenario 1 has a probability of 88%.

With the environmental benefits included in the analysis, the probabilities change slightly. The probability

Table 5. Stochastic efficiency analysis of scenario without environmental benefits.

	Slightly risk averse →				Extremely risk averse
Rank	0.00–0.0000082	0.0000083–0.0000166	0.0000167–0.0000666	0.0000667–0.0001332	>0.0002
1st	Scenario 1	Scenario 1	Scenario 3	Scenario 3	Scenario 3
2nd	Scenario 3	Scenario 3	Scenario 1	Scenario 1	Scenario 2
3rd	Scenario 4	Scenario 5	Scenario 5	Scenario 2	Scenario 1
4th	Scenario 5	Scenario 4	Scenario 2	Scenario 5	Scenario 5
5th	Scenario 2	Scenario 2	Scenario 4	Scenario 4	Scenario 4

Table 6. Stochastic efficiency analysis of scenarios with environmental benefits.

	Slightly risk averse →					Extremely risk averse
Rank	0.00–0.0000082	0.0000083–0.0000166	0.0000167–0.0000249	0.0000250–0.0001166	0.0001167–0.0001666	>0.0001667
1st	Scenario 1	Scenario 3	Scenario 3	Scenario 3	Scenario 3	Scenario 3
2nd	Scenario 3	Scenario 1	Scenario 1	Scenario 5	Scenario 5	Scenario 2
3rd	Scenario 4	Scenario 5	Scenario 5	Scenario 1	Scenario 2	Scenario 5
4th	Scenario 5	Scenario 4	Scenario 2	Scenario 2	Scenario 1	Scenario 1
5th	Scenario 2	Scenario 2	Scenario 4	Scenario 4	Scenario 4	Scenario 4

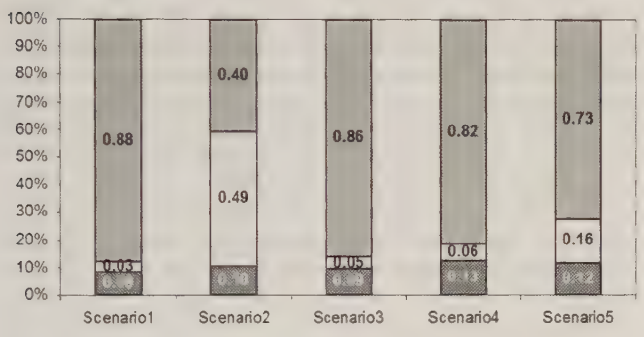


Figure 3. Probabilities of net returns to management and labor <US$0 and >US$100,000 for the simulation farm per year: environmental benefits are included into percentages.

of losses goes to 10% for scenario 2, 13 and 12% for scenario 4 and 5, respectively (Fig. 3). The probability of net returns higher than $100,000 goes to 40% for scenario 2, and 73% for scenario 5. For the other scenarios, the environmental benefits only slightly improved the probabilities of net returns higher than US$100,000.

In this analysis, the scenarios with the higher proportion of corn would be preferred over the scenarios with the higher proportion of grass. The environmental benefits slightly change the probabilities of net returns but not enough to change the ranking of preferred scenario.

Risk aversion. Simetar© allows the user to input different risk aversion coefficients (RAC) to analyze decision makers' choices under any level of risk. The interval is determined to be between an RAC of 0 when a producer is risk neutral, and an RAC of 0.0002 when a producer is risk averse (Table 5). When a producer is risk neutral, the preferred scenario is scenario 1. The remaining scenarios are ranked based on the corn proportion. As the RAC value increases to 0.0002 (risk averse), scenario 1 moves to the third preferred scenario and is replaced by scenario 3 (80% corn and 20% grass). Although the continuous corn scenario ranks high in most of the RAC categories, a high standard deviation causes it to drop in ranking when a decision maker becomes more risk averse. However, as producer risk aversion increases, the ranking increases for the two scenarios (2 and 5) with the highest proportion of grass.

When environmental benefits are included in the analysis, the ranking of scenarios for a risk neutral producer is the same as if the environmental benefits were not included. When a producer is risk averse, the ranking is almost similar, except for scenarios 1 and 5, which switch positions between third place and fourth place (Table 6). This means that, even if environmental benefits as calculated in this study are materialized and paid to farmers, the preferred scenarios would not change. The incentives from ecosystem services are not high enough to influence farmers' decisions.

The difference between continuous corn and all other scenarios is the risk premium that would be needed at the RAC to be indifferent between the two scenarios. When no environmental benefits are included in the analysis, scenarios 3 and 2 move above the continuous corn scenario as RAC increases, while scenarios 4 and 5 continue to rank below the continuous corn scenario. When the environmental benefits are included in the analysis, only scenario 4 never moves above the continuous corn scenario (Table 6).

These results also show that as producers become more risk averse, scenario 3 (80% corn and 20% grass) becomes the most preferred. A more risk-averse producer prefers minimal variation in net returns compared with fluctuating gains or losses and thus may prefer a mixture of corn and grass compared to continuous corn.

Discussion and conclusion

Switchgrass and mixed grass are starting to become a part of South Dakota agriculture, but as this study shows, it is far from producing the same net returns as corn production. The availability of better, more drought tolerant hybrids allowed corn to be preferred over perennial grass production. As corn hybrids become more advanced, and if corn prices and yields stay at the current level or higher, the conversion from corn production to prairie grasslands production is not expected to occur.

The future of grassland prairie production depends on potential commercial uses of grass. If switchgrass or mixed grasses are used as feedstock for ethanol, further research will be needed to increase yields and reduce costs. For switchgrass or mixed grass to be commercially viable, there must be available markets, and for producers to change their practices there must be a sufficient financial incentive. If the incentives have to be done on the environmental friendly characteristic of growing grasses, the main environmental attribute that policy makers should be focused on is carbon sequestration. In the United States, carbon trade was taking place on a voluntary basis; however, in some other global regions such as Europe, carbon trading is mandatory. This system could be developed in the US and may convince farmers to switch from conventional corn production to prairie grasslands. A green market could also be developed for the reduction in soil erosion and sedimentation in the rivers due to growing grasses. Also, increased grass production favors increases pheasant production and hunting, which may be another revenue source for landowners and producers.

Conducting similar studies in other regions of the USA would help to investigate and understand the incentive levels needed to convert cropland to grassland. If similar studies were to be conducted, a corn–soybean scenario should be introduced for a more realistic cropping pattern comparison in eastern South Dakota. Experimental data should also span a longer period. The first years of the conversion are the establishment period, and some experts think that switchgrass and mixed grass can easily reach a yield of 9–12 metric tons ha^{-1}. However, in the field plot data evaluated here the maximum yield is 6.9 metric tons ha^{-1}. Moreover, other output possibilities could be studied. Switchgrass and mixed grass do not yet have a commercial market; therefore, they are sold as valued hay for feeding. However in the future, they have potential to become one of the main sources of supply for second generation biofuels, and the value of a ton of switchgrass or mixed grass has the potential to increase compared to a ton of conventional hay. On the EcoSun Prairie farm, the main revenue comes from selling grass seed. Therefore, seed yields should be recorded and studied, and if the price of seed could be introduced, the net returns from grass are likely to increase. Grass can also be used as prairie to raise cattle, which can be sold as a high value product. For grass to be viable all these streams of revenue should be studied and a mix of all of them could be economically compared to corn and hay productions.

On the other hand, corn stover can be grazed or used as feedstock for ethanol production. Therefore, this could increase the corn dominance over grass production. The use of corn stover for ethanol production would increase the costs of growing corn because it would require special harvesting and handling methods. For now, no price is clearly determined; the value of corn stover depends on the costs of operating the ethanol plant, and the price of substitute products.

The result of this study provides some initial insight for ecosystem services valuation in east central and southeast South Dakota. Only three ecosystem services are considered in this study. Even if they are perceived as top priorities, other ecosystem services could be included. Moreover, with the uncertainty of the price and value of each ecosystem service, it may be useful to evaluate grass production with higher social cost of carbon, higher price for soil erosion, or pheasant harvest.

The overall conclusion of this paper is that the conventional continuous corn production consistently performs better than any of the other scenarios including grass production alone, in terms of profitability. The addition of ecosystem services values does not seem to provide enough incentives to convince farmers to convert their corn production to grass production. Higher payments from federal or state government for ecosystem conservation, and more competitive prices for all streams of grass production might provide incentives sufficiently high for farmers to switch from conventional cropland to grassland.

Acknowledgments. This project was supported by an award from the USDA-NRCS Conservation Innovation Grant program and by South Dakota State University Agricultural Experiment Station. Additional funding for research assistantship was provided by the South Dakota Corn Utilization Council and the South Dakota Soybean Research and Promotion Council.

References

1 Food and Agricultural Policy Research Institute. 2008. The energy independence and security act of 2007: preliminary evaluation of selected provisions. Congressional Staff Report FAPRI-MU #01-08. University of Missouri-Columbia.

2 Eisentraut, A. 2010. Sustainable production of second-generation biofuels; potential and perspectives in major

economies and developing countries. Information paper. International Energy Agency, Paris.
3 Greene, N. 2004. Growing Energy; How Biofuels can Help end America's Oil Dependence. Natural Resources Defense Council, New York.
4 English, B., De La Torre Ugarte, D., Menard, J., and West T. 2008. Economic and environmental impacts of biofuels expansion: the role of cellulosic ethanol. University of Tennessee, Department of Agricultural Economics.
5 Malcolm, S.A., Aillery, M., and Weinberg, M. 2009. Ethanol and a changing agricultural landscape. Economic Research Report 86. U.S. Department of Agriculture, Economic Research Service, Washington, DC.
6 Meyer, P.E. 2010. Biofuel Review Part 3: Land Availability, Conversion, and Deforestation. IEEE-USA Today's Engineer Online, Washington, DC.
7 Sesmero, J. 2011. Sustainability of corn stover harvest for biomass. Purdue University, Department of Agricultural Economics.
8 Heathon, E.A., Clifton-Brown, J., Voigt, T.B., Jones, M.B., and Long, S.P. 2004. Miscanthus for renewable energy generation: European Union experience and projections for Illinois. Mitigation and Adaptation Strategies for Global Change 9:433–451.
9 Trostle, R. 2008. Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices. U.S. Department of Agriculture, Economic Research Service, Washington DC.
10 Inter Agency Projections Committee. 2010. USDA Agricultural Projections to 2019, Long-Term Projections Report. Office of the Chief Economist, U.S. Department of Agriculture, Washington DC.
11 Pryor, F.L. 2009. The economics of gasohol. Contemporary Economic Policy 27(4):523–537.
12 Taxpayers for Common Sense. 2013. Political Footprint of the Corn Ethanol Lobby. Taxpayers for Common Sense, Washington, DC.
13 Khanna, M. 2008. Cellulosic biofuels: are they economically viable and environmentally sustainable? Agricultural and Applied Economics Association. Choices 23:3.
14 Mooney, D., Roberts, R., English, B., Tyler, D., and Larson, J. 2008. Switchgrass production in marginal environments: a comparative economic analysis across four west Tennessee landscapes. University of Tennessee, Department of Agricultural Economics.
15 Bangsund, D., Devuyst, E., and Leistritz, F. 2008. Evaluation of breakeven farm-gate switchgrass prices in south central North Dakota. Agribusiness and Applied Economics Report 632. North Dakota State University.
16 Song, F., Zhao, J., and Swinton, S. 2009. Switching to Perennial Energy Crops Under Uncertainty and Costly Reversibility. Staff paper 2009-14. Michigan State University Department of Agricultural, Food, and Resources Economics, East Lancing, Michigan.
17 Malcolm, S., Aillery, M., and Weinberg, M. 2009. Ethanol and A Changing Landscape. U.S. Department of Agriculture, Economic Research Service, Washington DC.
18 King, D., and Mazzotta, M. 2000. Ecosystem valuation. University of Maryland. Available at Web site: www.ecosystemvaluation.org. (accessed June 25, 2013).
19 Babcock, B., Gassman, P., Jha, M., and Kling, C. 2007. Adoption Subsidies and Environmental Impacts of Alternative Energy Crops. Briefing Paper 07-BP 50. Center for Agriculture and Rural Development, ISU, Ames. Iowa.
20 Gascoigne, W., Hoag, D., Koontz, L., Tangen, B., Shaffer, T., and Gleason, R. 2011. Valuing ecosystem and economic services across land-use scenarios in the Prairie Pothole region of the Dakotas, USA. Ecological Economics 70:1715–1725.
21 Natural Resources Conservation Services. 2011. Precision conservation using multiple cellulosic feedstocks. Final Report 69-3A75-7-117. South Dakota State University, College of Agricultural and Biological Sciences. South Dakota Experiment Station.
22 U.S. Department of Agriculture. 2007. Census of Agriculture. State Level Data, South Dakota.
23 Bourlion, N. 2012. Private and public benefits of innovative mix crop systems intended for biofuels production in eastern South Dakota. Masters thesis, South Dakota State University, Economics Department.
24 Interagency Working Group on Social Cost of Carbon, United States Government. 2010. Technical support document: social cost of carbon for regulatory impact analysis - Under Executive Order 12866.
25 Iowa State University Extension and Outreach. 2011. 2011 Iowa farm custom rate survey. Agricultural Decision Maker.
26 Janssen, L. and Pflueger, B. 2011. South Dakota Agricultural Land Market trends: South Dakota Agricultural Land Market Trends. SD Agricultural Experiment Station, Brookings, SD.
27 U.S. Department of Agriculture, National Agricultural Statistics Services. 2010. Crop Production. State Level Data, South Dakota.
28 U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, U.S. Census Bureau. 2006. 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.
29 Heimerl, K. 2011. Comparison of soil within a till plain across contrasting land uses. Masters thesis, South Dakota State University, Plant Science Department.
30 Mitchell, C. and Everest, J. 1995. Soil testing and plant analysis: interpreting soil organic matter tests. Southern Regional Fact Sheet. Auburn University, AL, Department of Agronomy and Soils.
31 Allmaras, R., Schomberg, H., Douglas, C., and Dao, J. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. Journal of Soil and Water Conservation 55(3):365–373.
32 Hill, J., Polasky, S., Nelson, E., Tilman, D., Huo, H., Ludwig, L., Neumann, J., Zheng, H., and Bonta, D. 2009. Climate change and health costs of air emissions from biofuels and gasoline. Proceedings of the National Academy of Sciences USA 106(6):2077–2082.
33 Hansen, L. and Ribaudo, M. 2008. Economic measures of soil conservation benefits; regional values for policy assessment. ERS-USDA Technical Bulletin 1922.
34 Nielson, R., McDonald, L., Sullivan, J., Burgess, C., Johnson, D., and Howlin, S. 2006. Estimating response of ring-necked pheasant (*Phasianus colchicus*) to the conservation reserve program. Technical Report Prepared for U.S. Department of Agriculture Farm Service Agency.
35 Richardson, J., Shumann, K., and Feldman, P. 2008. Simetar© Simulation and Econometrics to Analyze Risk. Excel Add-in Program, College Station, TX.

Renewable Agriculture and Food Systems: 29(4); 366–377 doi:10.1017/S1742170513000240

Assessment of on-farm conservation of dryland agrobiodiversity and its impact on rural livelihoods in the Fertile Crescent

Ahmed Mazid*, Kamil Shideed and Ahmed Amri

The International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syrian Arab Republic.
*Corresponding author: a.mazid@cgiar.org

Accepted 1 June 2013; First published online 10 July 2013 **Research Paper**

Abstract

The Fertile Crescent encompasses a mega-center of diversity of crops and livestock of global importance. The International Center for Agricultural Research in the Dry Areas (ICARDA) coordinated a 5-year regional project funded by the Global Environment Facility to promote *in situ* conservation of dryland agrobiodiversity in Jordan, Lebanon, the Palestinian Authority and Syria. The project focused on conserving landraces and wild relatives of *Allium, Vicia, Trifolium, Medicago* and *Lathyrus* spp. and barley, wheat, lentil and dryland fruit trees (olive, prune, pear, pistachio, almond, cherry and apricot). ICARDA and national programs assessed the status and importance of local agrobiodiversity by surveying 570 farm households in the project target areas including the characterization of their livelihood strategies, agrobiodiversity use and household income sources. A wealth index was created considering human, natural, financial, physical and social assets and was used to classify households into four wealth quartiles. The results indicated that agriculture and agrobiodiversity continue to be important for supporting the livelihoods of poor communities in dry and mountainous regions. The poorest households obtained their income from diverse sources including crop production, off-farm labor and government employment. However, households in the highest wealth grouping are mainly dependent on income from selling livestock products and live animals. They also practiced crop production, worked off-farm and took advantage of government employment. Off-farm income was important for livelihoods in all areas, representing 43–68% of household incomes. For all groups, fruit trees were generally more important than field crops for income generation, mainly in mountainous areas. The finding of this study showed that all farmers' groups contribute greatly to on-farm conservation of landraces, with a bigger role for poor farmers in conserving the landraces of fruit trees. Diversification of income and farming systems to include livestock, field crops and fruit trees along with off-farm activities are contributing to the conservation of agrobiodiversity in these marginal environments. Several opportunities for income increase and diversification through add-value activities and alternative sources of income are demonstrated to the custodians of dryland agrobiodiversity. Their benefits can contribute to the sustainability of agrobiodiversity conservation, provided that marketing of local products can be enhanced.

Key words: dryland agrobiodiversity, landraces, *in situ* conservation, livelihood analysis, Fertile Crescent

Introduction

Agrobiodiversity occupies a unique place within biological diversity, as it relates directly to sustainable food security and agricultural development. It is actively managed by farmers and therefore inherited indigenous knowledge is an integral part of this agrobiodiversity. The importance of dryland agrobiodiversity in particular has been emphasized by the Convention on Biological Diversity[1] as it relates to the livelihoods of poor rural communities and to crops and livestock of global significance.

West Asia encompasses one of the three mega-centers of diversity of global importance, where wheat, barley, lentil and many forage legume and fruit tree species were domesticated over the past 10,000 years[2–4]. Traditional farming systems, rich in landraces and wild relatives of these crops and local breeds of livestock continue to provide the basis for sustaining the livelihoods of local communities living in dry areas and mountainous regions. The loss of biodiversity in general and agrobiodiversity in particular is occurring at an alarming pace due mainly to anthropogenic factors (including overuse, land use changes and introduction of new varieties and crop

© Cambridge University Press 2013

species) in addition to the major threats of climate change and land degradation[5,6].

The conservation and sustainable use of agrobiodiversity are critical to realizing the Millennium Development Goals and Agenda 21 objectives[7,8]. The conservation and availability of agricultural biodiversity will become increasingly important to pursue breeding efforts and also in the context of rehabilitation of degraded ecosystems, adaptation to climate change and greater resilience.

The Convention on Biological Diversity[1] and the International Treaty on Plant Genetic Resources for Food and Agriculture[9] call for collective efforts among countries for effective conservation and sustainable use of agrobiodiversity. They both emphasized the use of *in situ* and on-farm conservation strategies to complement the ongoing efforts of conservation of genetic resources in gene banks. *In situ* conservation incorporates two distinct approaches: conservation of wild species in natural habitats and on-farm conservation of domesticated varieties or local breeds. On-farm conservation managed by farmers and its promotion should be directly linked to enhancing the livelihoods of its custodians[10]. Local varieties (landraces) are still used in traditional farming systems and by subsistence farmers and are an important source of valuable genes for breeding programs.

Bioversity International (previously the International Plant Genetic Resource Institute) has conducted several projects in several countries on promoting on-farm conservation of crop landraces which allowed a better understanding of the status and threats to local agrobiodiversity and the development of approaches for its on-farm conservation and sustainable use [11,12]. On-farm conservation managed by farmers and its promotion should be directly linked to enhancing the livelihoods of these farmers[10]. Local varieties (landraces) are still used in the traditional farming systems and by subsistence farmers and are an important source of valuable genes for breeding programs.

The International Center for Agricultural Research in the Dry Areas (ICARDA) has coordinated a five-year project entitled 'Conservation and Sustainable Use of Dryland Agrobiodiversity' launched in 1999 to promote *in situ* conservation and sustainable use of dryland agrobiodiversity in Jordan, Lebanon, the Palestinian Authority and Syria with funding from the Global Environment Facility (GEF) through the United Nations Development Programme (UNDP)[6,13]. The project developed a holistic approach for promoting *in situ* conservation of landraces and wild relatives including technological, institutional and policy options in addition to value-adding technologies, alternative sources of income and access to markets for custodians of agrobiodiversity, and awareness increase for the general public[6].

This paper aims to show the status of agrobiodiversity and the impacts of some of these project activities on the livelihoods of rural communities living in the drylands. The hypothesis of this study was that agrobiodiversity conservation would generate enough income for farmers thus improving their livelihood, particularly for small scale farmers, to sustain conservation. Added-value and income-generating activities are evidence for support of this hypothesis.

Materials and Methods

This activity was part of the project on 'Conservation and Sustainable Use of Dryland Agrobiodiversity' and was executed in Jordan, Lebanon, the Palestinian Authority and Syria[13]. The project strategy was to develop community-driven *in situ* and on-farm agrobiodiversity conservation initiatives in representative areas of global agrobiodiversity significance. The combining of specialized international and regional institutions with national institutions in the project greatly enhanced the synergy of the project, and awareness promotion was a priority at all project levels. Innovative approaches to *in situ* and on-farm conservation were developed alongside appropriate resource management to maintain the productivity of resources and economic viability of the community. The project strengthened institutional and community capacity, to promote a progressively greater national contribution to agrobiodiversity conservation and management.

The argument of this paper is that generation of cash income is the way in which development projects traditionally are expected to create incentives for conservation and sustainable use of natural resources[14,15]. Alternatively, this study focuses on livelihoods as a more appropriate measure of what the project meant to local people, and therefore of its likely contribution to development and agrobiodiversity conservation. The rationale for this was grounded in greater understanding of poverty, such as the importance of assets, diversified portfolios of activities and the variety of outcomes pursued by the poor.

The project was managed as five components. Each of the four participating countries had its own nationally executed component, whereas regional coordination was done by ICARDA. The project activities were implemented at the national level by national research institutes: the National Center for Agricultural Research and Technology Transfer (NCARTT) in Jordan, the Lebanese Agricultural Research Institute (LARI) in Lebanon, the General Commission for Scientific Agricultural Research (GCSAR) in Syria and the Ministry of Agriculture and UNDP/PAPP in the Palestinian Authority.

Target areas were selected to capture maximum genetic diversity of the target crops in a minimum number of areas. Thus, they were selected for the presence of target species, to be representative of major and complementary ecosystems, and suitability of working conditions, which include willingness of local communities to participate,

Table 1. Some characteristics of agrobiodiversity in the target areas in the four countries.

Country/target areas		Target area main characteristics
Jordan	Ajloun	Mountainous area with steep slopes and valleys, 75 km north of Amman. Sub-humid Mediterranean climate, 80% of soils are shallow. Vegetation cover mainly indigenous forest of *Pinus* and *Quercus* with wild species of pistachio, plum and almond. Wild relatives of cereals and forage species found in undisturbed areas and in agricultural landscapes. Overgrazing and land reclamation are major threats to biodiversity. Two natural reserves are located in this region
	Muwaqqar	A dry area located on the plateaus and hills south of Amman, representing the steppe zone. Highly calcareous soils eroded by wind and water. Open grazing and barley growing are predominant land uses. Supplementary-irrigated olive orchards are developing. Wild barley, wild species of *Aegilops, Vicia* and *Lathyrus* and local varieties of olive, grapes, figs and almonds found in a few irrigated orchards and home gardens. Jordan University has introduced *Atriplex* spp. and is experimenting with water harvesting techniques. Overgrazing is the major threat to biodiversity. Urbanization and expansion of barley and olive cultivation is restricting the range areas
Lebanon	Baalbak	A flat plateau rising steeply on one side to 1700 m. Includes the localities of Nabha (west of Beqaa in the Lebanon mountains) and Ham-Maaraboun (east, Anti-Lebanon mountains). Semi-arid climate, highly calcareous soils. Dryland farming of field crops and fruit tree orchards are predominant. Over 500 plant species, of which many are endemic. Wild relatives of cereals, legumes and fruit trees are found. Habitat fragmentation, deforestation and overgrazing are threatening wild relatives; landraces being replaced by improved cultivars or introduced fruit trees
	Aarsal	It is part of the Anti-Lebanon mountain range with climate ranging from arid to semi-arid. Soils are predominately calcareous and alluvial soils are found in the valleys. The area is used for open grazing and to grow barley and wheat. The planting of grapes and cherries is progressing. Wild relatives of cereals, legumes and fruit trees and many forage species are found in very restricted areas. Overgrazing and quarries are the main factors of degradation of natural habitats and local agrobiodiversity
Palestinian authority	Jenin	Hilly region sloping down to the Jordan Valley, climatic gradient from semi-arid to arid. Soils are alluvial and dark Rendzina with some basaltic pockets that are lost through overgrazing. Natural reserves exist. Cereals, food legumes, vegetables and olive trees cultivated. Wild species of cereals, legumes and forage species are found, threatened by habitat destruction and overgrazing
	Hebron	Includes the mountain slopes of Hebron and the nearby hills in the south and east. Semi-arid Mediterranean climate. Terra Rossa soils predominate in the mountains, alluvial soils in plains and valleys. Landraces as well as many wild relatives of cereals, food and feed legumes and fruit trees are found. Overgrazing (and quarries in some areas) are the major threats to agrobiodiversity
	Al-Haffeh	Extends from 500 to 1000 m altitude on the Slenfe mountain. Humid and sub-humid climate with Mediterranean influence. Forest containing wild species of fruit trees predominates. In cultivated areas, landraces of cereals, food legumes and fruit trees are still used. Deforestation, land reclamation, overgrazing and expansion of olive and citrus plantations are threatening biodiversity
Syria	Sweida	Mainly mountainous area with a climate ranging from sub-humid to arid. Soils of basaltic origin. Dryland farming with cereals, food legumes and forages. New plantations of apple trees and grape vines are expanding rapidly. Unique area for biodiversity, with 900 wild species of cereals, food legumes and pistachio. Overgrazing, expanding apple orchards and destruction of natural habitats are affecting biodiversity significantly

and the potential for impact. In each participating country, two target areas were selected, and 2–6 sites chosen in each target area to include the diversity of environments and farming systems (Table 1 and Fig. 1).

To review the project's achievements, a full socio-economic assessment of its preliminary impacts was conducted in 2005, following the baseline survey conducted in 1999–2000. ICARDA's social scientists implemented this study in collaboration with national teams. The study covered the eight target areas (two per country) in the four participating countries. The main objectives of this study were to assess the impact of the project on conserving agrobiodiversity in targeted areas and to assess the effect of value-adding, including income-generating activities introduced by the project on livelihoods of rural communities.

After a group discussion with farmers in the target area, a formal questionnaire was prepared and tested. Each national team carried out fieldwork activity for data collection in its respective target areas. Each enumerator utilized one questionnaire per respondent. The questionnaire focused on collecting data on the following main

Figure 1. Locations of the target areas in the four countries.

themes:participation in the project; household structure and income source; characterization of household livelihood strategies; cropping systems and cultural practices; changes in land use; seed and seedling use and exchange; household assets; gender activities and farmers' perceptions of the project.

Household samples were selected and interviewed in the target areas in Jordan, Lebanon, the Palestinian Authority and Syria. The sample farms were grouped in terms of their participation in the project into: (1) Participants in agrobiodiversity technology enhancement activities, which include seed treatments, seed distribution, water harvesting for fruit trees, water harvesting for shrubs, fruit tree nurseries, nurseries for rangeland shrubs, reforestation, field genebanks and revegetation and rehabilitation rangeland. (2) Participants in value-added, income-generating activities, which include organic farming, bee keeping and honey production, food processing especially jam, dairy processing, mushroom production, medicinal plants cultivation, home gardens and feed blocks. (3) Participants in field days, training and educational programs that include fairs control, meetings and workshops, training courses on jams, dairy processing, honey and mushroom production. (4) Non participants that were randomly selected within the same communities.

Many criteria were used for selection of the participants, including being known custodians of agrobiodiversity by the community, willingness to participate and contribute financially to the project and to be part of any grouping to be formed by the interested farmers.

The survey sample included 570 households: 276 that had participated in the project and 294 that had not. Given the homogeneity among the target areas, a random sampling approach was used. According to Collinson[16], 50–60 farmers was a sufficient sample size, and hence, the sample size in this study included about 70 households randomly selected in each target area, about 40–60% of them had participated in the project activities, and the remainder had not. Table 2 shows the sample size in each country and sample farms' classification by type of participation in the project.

Table 2. Classification of sample farms by type of participation in the four countries (% of households).

Type of participation	Jordan	Lebanon	Palestine	Syria
Agrobiodiversity enhancement	15	30	60	33
Value-added, income-generating activities	7	9	0	10
Field days and training	17	5	1	7
Non participants	61	56	39	50
Sample size (*N*)	145	138	140	147

A sustainable livelihood framework was used to characterize households in the study areas. Livelihood strategies, agrobiodiversity use and incomes were compared within and across all countries studied, among poor and better-off households, by using a principal components analysis to create a wealth index that accounted for five types of capital of a household: human, natural, financial, physical and social. The wealth index in this study utilized some household assets indexes such as cropland, rangeland, livestock, vehicles and houses, on- and off-farm incomes, access to credit, cooperatives and health care. Based on these variables, households were classified into four wealth groupings (quartiles), each corresponding to 25% of the range of values obtained for the wealth index. Impact assessment in terms of household income was calculated; and a factor related to equality had to be taken into account by calculating the Gini coefficient to assess equity in incomes within participating and non participating households in each country. The Gini coefficient is a number within 0–1, where 0 is perfect equality (i.e., everyone has the same income) and 1 is perfect inequality (i.e., one person has all the income, and everyone else has zero).

Results and Discussion

Assessment of status and threats for local agrobiodiversity

The predominant farming system depends mostly on environmental conditions, mainly topography and climate (Table 3). In the rangeland-dominated areas, i.e., Muwaqqar in Jordan, and Aarsal in Lebanon, livestock is the only activity for 77 and 53% of households, respectively. In these two sites, the remaining farmers mainly planted rainfed barley and had olive trees under irrigation in Muwaqqar; and correspondingly vetch and cherries in Aarsal. In the mountains of Ajloun in Jordan and Al-Haffeh in Syria, 66 and 80% of farmers,

Table 3. Predominant types of farming systems in target areas in the four countries (% of households).

	Jordan		Lebanon		Palestine		Syria	
Type of enterprise	**Muwaqqar**	**Ajloun**	**Aarsal**	**Baalbak**	**Hebron**	**Jenin**	**Sweida**	**Al-Haffeh**
Crops only	10	66	24	58	44	42	54	80
Livestock only	77	14	53	8	2	1	2	0
Crops and livestock	13	20	18	34	54	57	44	20

Table 4. Average number of fields and crops per farm and crop diversity index in target areas.

	Jordan		Lebanon		Palestine		Syria	
Item	**Muwaqqar**	**Ajloun**	**Aarsal**	**Baalbak**	**Hebron**	**Jenin**	**Sweida**	**Al-Haffeh**
Number of fields per farm	2.25	2.45	3.59	4.23	5.00	4.72	4.91	2.58
Number of crops per farm	2.25	3.86	4.43	4.18	4.84	4.47	4.69	2.89
Crop diversity index	1.00	1.58	1.23	0.99	0.97	0.95	0.96	1.12

respectively, grew mainly fruit trees and 20% practiced both cropping and livestock raising. In Al-Haffeh, no farmers had small ruminants; and in Ajloun farmers mainly raised goats in semi-intensified systems. In the remaining target areas, the farmers were split between crop-producing and crop–livestock producers and only 1–8% were exclusively herders. These results show the great diversity of farming systems, and the importance of livestock in drier and flatter areas and of fruit trees in mountainous areas. In Palestine, the lower number of herders might be due to restricted access to rangelands due to the prevailing political situation. The importance of crop–livestock systems is an important attribute of farming systems in arid and semi-arid areas and contributes to buffering of the effects of droughts, with the livestock playing an important role in providing cash to farmers[6].

The second indicator of local agrobiodiversity is shown by the number of crops used at the farm level. The range in average numbers of crops grown per farm was 2.25–4.84 (Table 4), showing that farmers in all agroclimatic zones tended to grow >2 crops. However, the highest numbers were in mountainous and high rainfall areas. In these latter systems, several crop species can be grown in the same field, as indicated by the crop diversity index. In Ajloun and Al-Haffeh, some farmers' fields had up to 15 crops, with mainly fruit trees in the top layer and field crops in the lower layer. Some farmers even planted medicinal plants and vegetables under fruit trees. Among the predominant fruit trees were olive, apple, grapes, cherries and figs in Ajloun, Sweida and Al-Haffeh; and among field crops were barley, wheat, lentil, chickpea and vetch. This diversity of crops contributes to the diversification of the diet of local communities, the feed calendar of livestock and the diversification of sources of income, and also allows for the spread of labor needs over the whole year.

The third indicator of agrobiodiversity investigated was the number of landraces known or still in use by farmers. For fruit trees, large numbers of landraces were cited by farmers, including more than ten landraces of olives, 20 of grapes, 15 of figs, five of cherries, two of almonds, three of apples, three of apricots and four of plums. Improved varieties are mainly used in the cases of apples, cherries and apricots. For barley, lentil and chickpea, the commonly designated local landraces could include several populations.

Farmers have acknowledged the disappearance of some landraces of all crops and have attributed this to limited efforts to multiply their seeds within the existing informal seed production system and fruit tree nurseries. Marketing problems and storability could also have contributed to the decrease in importance of landraces. Another major threat to local agrobiodiversity is related to loss of local knowledge due to limited interest of young generations to invest and work in agriculture. However, the farmers appreciated landraces of most crops for their adaptation to low-input conditions and to major biotic and abiotic stresses. In addition, these landraces had good quality attributes that give the products of these landraces a price premium in the market.

Farmers were asked if they had degradation on their farms, its sources and effects on agrobiodiversity (Table 5). The three major degradation factors mentioned were overgrazing, introduction of new species and land reclamation. The source of degradation varied between locations. In Jordan, overgrazing, deforestation and urbanization were the three main sources. Overgrazing and introduction of new species were the two main sources of degradation in Lebanon. In Palestine, the major threats to agrobiodiversity were overgrazing, soil erosion, introduction of new species and urbanization in both Hebron and Jenin; however, quarries and land reclamation were sources of degradation in Hebron and Jenin, respectively.

Table 5. Sources of degradation of local agrobiodiversity (% of farmers).

	Jordan		Lebanon		Palestine		Syria	
Degradation sources	**Ajloun**	**Muwaqqar**	**Aarsal**	**Baalbak**	**Hebron**	**Jenin**	**Sweida**	**Al-Haffeh**
Overgrazing	38.7	71.4	31.5	41.5	97.1	84.3	1.4	1.4
Land reclamation	5.3	0.0	12.3	29.2	18.6	38.6	0.0	1.4
Deforestation	44.0	0.0	11.0	6.2	4.6	0.0	0.0	4.2
Erosion	28.0	30.0	6.8	6.2	75.7	32.9	9.5	26.4
Affected by new species	4.0	0.0	20.5	27.7	44.6	40.0	0.0	26.4
Affected by fire	8.0	0.0	1.4	1.5	6.2	24.3	2.7	0.0
Affected by quarries	8.0	5.7	9.6	1.5	41.4	0.0	0.0	23.6
Affected by urbanization area	54.7	4.3	1.4	6.2	89.9	91.4	0.0	23.6

In Syria, only in Al-Haffeh were erosion, introduction of new species and urbanization the main sources of degradation.

Household assets and socio-economic characterization

Household characteristics are based on the main household assets, including natural, physical, financial, human and social capitals. Total holding area per household ranged from 0.9 ha at Al-Haffeh in Syria to 17.5 ha at Muwaqqar in Jordan. Most farmers in the target areas owned their agricultural land, except in Muwaqqar, where some farmers either rented land from landlords or had sharecropping arrangements. Common rangelands were available for the majority of households, except in Jordan, where this type of land was available for only 20% of households in the target areas. Drinking water is available for most households, except in Sweida where only 7% of households reported they had a drinking water source in the community, whereas the others have to bring drinking water from other villages or from the town of Sweida. Water resources for irrigation were very limited and the percentage of irrigated area in farms was low and insignificant for all target areas.

Average family size was 7–13 persons per household. Labor opportunities outside the target area ranged from 6% at Hebron in Palestine to 45% at Haffeh in Syria. Wage laborers were available when needed in all target areas, except in Muwaqqar, where shepherds were mainly needed. Although some household heads were illiterate, others held a university degree. Generally, the education level among households in the target areas was higher in Jordan and Palestine compared to Syria and Lebanon. Most farmers classified their livelihood levels as moderately well-off, except Ajloun in Jordan, where 44% of responders classified themselves as well-off.

Off-farm income was important in all target areas and represented 43–68% of total income. Average annual household income ranged from US$2200 to 9000 in the target areas, implying that daily per capita income was < US$1–5. Income per person per day was around US$2 in Jordan, Lebanon and Jenin (Palestine), but < US$2 in Syria and Hebron (Palestine). However, off-farm income is crucial for sustaining the livelihoods of local communities and allowing them to continue their contribution to the conservation and sustainable use of agrobiodiversity, mainly when the alternative sources of income are linked to valorization of local products. In areas where there is little opportunity for off-farm employment, incentive payment for environmental services is an option[17] that needs to be pursued.

Agricultural cooperatives were available in the target areas but most farmers in the sample were not members, except in Sweida in Syria where about 85% of responders reported that they were members of a cooperative. Most farmers in the target areas owned their houses, but very few farmers owned a tractor, car or pick-up. Many farmers in the sample had livestock—sheep, goats or cows—but flock size varied among the target areas. Flocks were larger in dry compared to wetter areas. Schools, public clinics, electricity and telephones were available to most households in target areas. Most households had a separate kitchen in their house, and a satellite dish and TV. Houses had an average of five rooms.

Sources of household income

Household farmers in the target areas had many activities as part of their livelihoods. They had many income sources, and there was variation in the amount and contribution of income sources among the four countries. Income from on-farm activities including returns from crops and fruit trees, livestock products and live animals represented <50% total household income in the four countries. Income from government employment was important in Jordan (48%) and Syria (20%), whereas income from off-farm (non agriculture) was important in Lebanon (34%) and Palestine (26%). Livestock was the main source of on-farm income in Jordan, whereas plant production (crops and fruit trees) was the major source in Lebanon, Palestine and Syria.

Contribution of alternative income sources to total household income was diverse, according to target areas in each country (Table 6). In Jordan, income from government employment was significant in Muwaqqar

Table 6. Contribution of alternative sources to total household income by target area (%).

	Jordan		Lebanon		Palestine		Syria	
Income source	**Muwaqqar**	**Ajloun**	**Aarsal**	**Baalbak**	**Hebron**	**Jenin**	**Sweida**	**Al-Haffeh**
Crops & fruit trees	1	38	19	38	22	31	34	34
Livestock products	20	7	5	7	4	7	6	3
Live animals	17	4	8	5	12	20	3	6
Total on-farm income	**38**	**49**	**32**	**50**	**38**	**58**	**43**	**43**
Off-farm (agriculture)	3	3	4	2	2	4	1	1
Off-farm (non agriculture)	3	6	45	22	39	12	2	17
Government employment	54	39	10	11	12	17	12	39
Remittances (outside country)	2	3	0	1	0	0	6	0
Other source	0	0	9	14	9	8	36	0
Total off-farm income	**62**	**51**	**68**	**50**	**62**	**42**	**57**	**57**

Table 7. Wealth quartiles (% of households) in the target areas in the four countries.

		Wealth quartiles (%)				
Country	**Site**	**Lowest 25**	**25–50**	**50–75**	**Highest 25**	**Total (%)**
Syria	Sweida	17.3	25.3	17.3	40.0	100.0
	Al-Haffeh	31.9	26.4	33.3	8.3	100.0
Palestine	Hebron	32.9	10.0	24.3	32.9	100.0
	Jenin	17.1	38.6	27.1	17.1	100.0
Lebanon	Aarsal	20.5	32.9	28.8	17.8	100.0
	Baalbak	29.2	16.9	20.0	33.8	100.0
Jordan	Ajloun	41.3	29.3	16.0	13.3	100.0
	Muwaqqar	8.6	20.0	32.9	38.6	100.0

followed by income from livestock; whereas at Ajloun, income from crops and fruit trees was important. In Lebanon, household income from off-farm activities outside agriculture was the main source in Aarsal; and income from crops and fruit trees was the major income source in Baalbak. However, there were many factors that influenced the contribution of alternative sources to total household income: e.g., farm resource availability, farmers' education, skills and experience and opportunities for off-farm activities.

The wealth index

The livelihood analyses in this study were focused on how income sources differed between households in the four countries and among the target areas; therefore, there was a need to use one indicator for comparisons. This indicator was the wealth index, which was based on the status of the households' assets. The calculated wealth index was used to rank households of a community.

In the wealth ranking, variables were identified by the key factors of principal components analysis as important in distinguishing households from each other in each country. Cavendish[18] in household studies from Shindi Ward in Chivi area in Zimbabwe, and Campbel et al.[19] in a study on household livelihoods in semi-arid regions, used wealth quartiles to explore patterns of income distribution. We undertook a similar analysis and calculated the wealth index as the most important factor to characterize household livelihoods and differentiate wealth levels.

Five main elements were hypothesized to represent household wealth situation. These elements included human, natural, financial, physical and social capitals as presented in the subsection 'Household assets and socio-economic characterization'. Several variables were selected and used to represent each element.

The wealth index was sorted into categories and classified households in the sample into four welfare quartiles. The distributions of households among the wealth quartiles were not the same in different target areas (Table 7). For example, most farmers in Sweida were in the highest wealth quartile; whereas, only 8% of farmers in Al-Haffeh were in the highest wealth quartile.

Livelihood strategies

Sources of household income by wealth quartiles. Household income from all sources was calculated and summarized (Fig. 2). Income from all sources increased with increasing wealth quartile. Percentage of income from crop production and off-farm labor wages

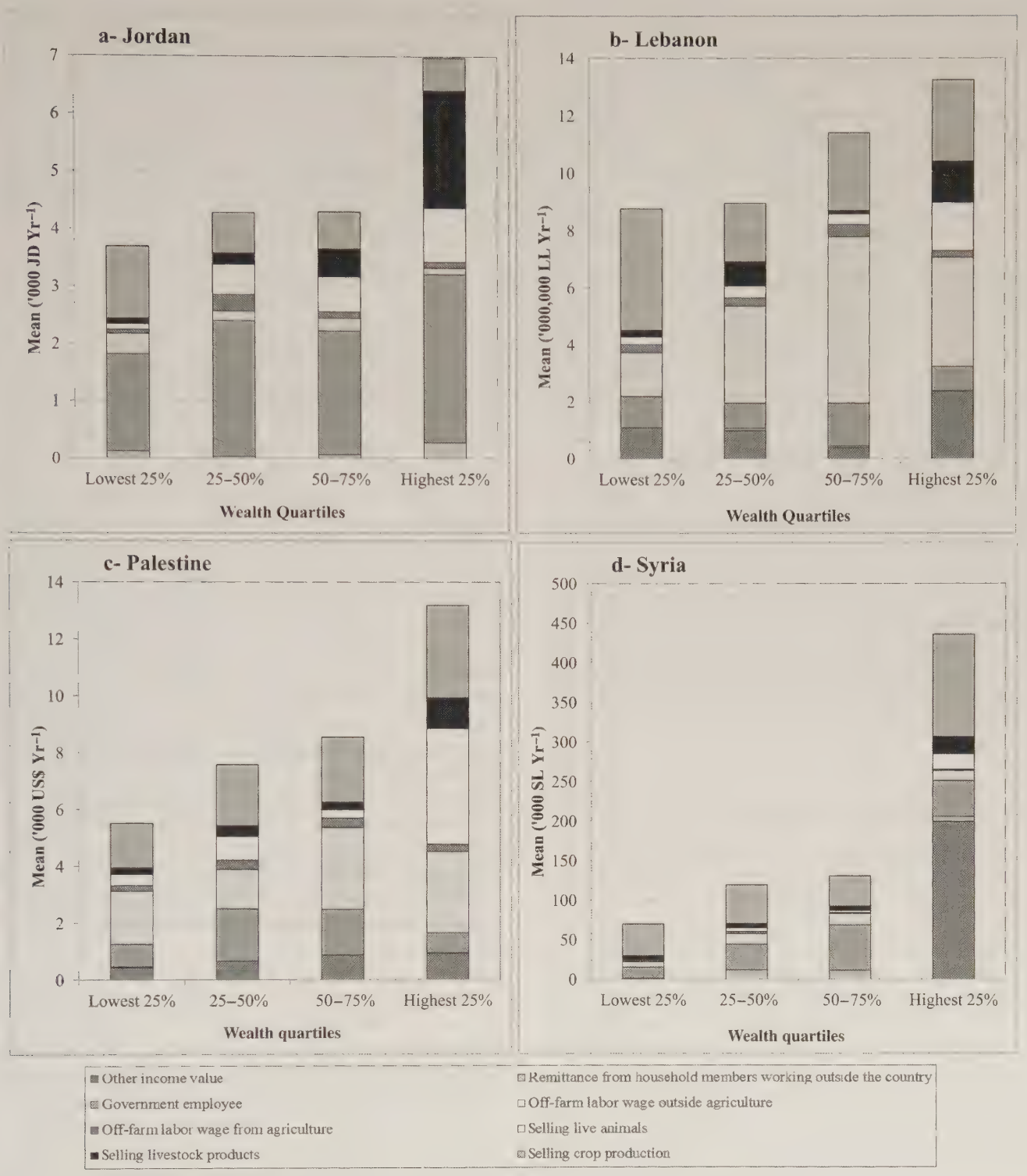


Figure 2. Income sources in the target areas by country and wealth quartiles.

from agriculture were generally higher in the lowest 25% compared to other groups.

Livelihood typologies. Livelihood strategies are diverse[20] and are influenced by linkages inside and outside agriculture[21–23], and life-cycle family characteristics such as age, education and number of family members[24,25]. The degree of diversification of the household portfolio is determined by these characteristics, and by the household's and individual's objectives, such as risk management practices, and/or strategies available to cope with shocks. In areas of greater risk, the household strategies are expected to be more diversified as a means to minimize possible shocks from negative climate events, especially when loss-management strategies are limited[26].

Table 8. Main sources of household income in the target areas in the four countries.

Wealth group (%)	Jordan	Lebanon	Palestine	Syria
Lowest 25	Government	Crops	Off-farm labor	Crops
	Crops	Off-farm labor	Crops	Government
	Off-farm labor	Government	Government	Off-farm labor
25–50	Government	Off-farm labor	Crops	Crops
	Crops	Crops	Government	Government
	Off-farm labor	Government	Off-farm labor	Off-farm labor
50–75	Government	Off-farm labor	Off-farm labor	Crops
	Crops	Crops	Crops	Government
	Live animals	Government	Government	Off-farm labor
	Livestock products			
Highest 25	Government	Off-farm labor	Live animals	Crops
	Livestock products	Crops	Off-farm labor	Government
	Live animals	Others	Crops	Others
	Crops	Live animals	Livestock products	Livestock products
				Live animals

Overall, households in the study areas depended on many sources for their income (Table 8). The main sources for households in the lowest 25% quartiles in the four countries came from crop production, followed by off-farm labor and government employment. The highest welfare quartile was relatively more dependent on livestock products and selling of live animals, in addition to crop production, off-farm labor and government employment. However, the lowest quartiles were relatively more dependent on livestock compared to those in the highest quartiles.

Impact on household income and livelihoods

Previous assessments of the project indicated very encouraging impacts, and helped in the setting-up of agrobiodiversity programs in research institutions in Jordan, Lebanon and Syria; and in the creation of agrobiodiversity units in the Ministry of Agriculture of the Palestinian Authority and in the Forestry Department in Jordan. There has been a shift toward the use of wild relatives of fruit trees in forestation efforts. In Syria, 500,000 seedlings of target landrace species were planted in 2003, compared to 30,000 in 1999. Awareness has increased at all levels regarding the need to conserve agrobiodiversity. This has facilitated collaboration with tourism and education ministries and with other projects and nongovernmental organizations. Sites rich in agrobiodiversity have been identified and designated so by governments, after approval by local communities. Many accessions of target species have been collected and placed in gene banks. Protocols for ecogeographic/botanic survey database management have been set up and a policy framework developed and shared.

However, the impact assessment also explored a wide variety of changes or trends caused by the project in terms of financial and livelihood impacts, and hence, the impact assessment differed from conventional project reviews in two ways. (1) It assessed impacts in terms of broad economic and livelihood change, not in terms of predefined project objectives and plans. This was because it sought to identify overall contribution to development, not to only assess accomplishment of planned activities for internal management purposes. Changes in livelihoods were adopted as a key measure of impact. (2) An assessment of commercial viability was an integral component, because the project interventions affected different household enterprises, and hence, viability determined sustainability. The commercial assessment was a complement to, rather than a component of, the analysis of local economic and livelihood impacts.

The impact assessments in this study explored changes and trends caused by the project for the households in the target areas, and analyzed these in terms of their financial and livelihood impact. Therefore, households who participated in the project were compared in terms of type of participation, wealth quartiles and income from agriculture, with those who did not participate in the project.

Increasing the average agricultural income is not necessary to have a positive effect on poor farmers, and other factors related to equity have to be taken into account. There are several ways to express the degree of income inequality in a society. As in many other studies[27], the Gini coefficient is used in this study to measure income inequality. The main advantage of the Gini coefficient is that it is a measure of inequality of income—focusing more on the distribution and not on the central tendency as is the case with averages and medians, which can often be affected by the relative size of a few outliers.

The analysis of income from agriculture indicated higher average household incomes for households that participated in the project compared to households that did not. The estimated Gini coefficients varied among participating and non participating households.

The comparison was done between participants and non participants within each group of the wealth

Table 9. Comparison between average household income from agriculture by participation in agrobiodiversity enhancement activities (US$/household).

Groups	Wealth quartiles (%)	Jordan		Lebanon		Palestine		Syria	
		Average US$	Gini coefficient	Average US$	Gini coefficient	Average US$	Gini coefficient	Average US$	Gini coefficient
Participants	Lowest 25	1923		4527		2765		1056	
	25–50	1274		3167		2765		2071	
	50–75	5070		3973		3105		1207	
	Highest 25	11,186		6195		6266		4265	
	Total	4280	**0.591**	4298	**0.401**	3897	**0.463**	2487	**0.477**
Non participants	Lowest 25	1473		2670		2125		1069	
	25–50	2103		2179		5390		954	
	50–75	2399		1460		3286		976	
	Highest 25	3577		3268		15,295		2663	
	Total	2526	**0.438**	2384	**0.391**	5351	**0.559**	1339	**0.476**

quartiles, which were classified based on household assets by using sub-indexes including cropland area, rangeland area, owned livestock numbers, vehicle and house ownership, on- and off-farm activities, access to credit, cooperatives membership and health care. Statistical analysis indicated that there were no significant differences between the averages of these variables in each wealth quartile. Therefore, notable increase in annual household income (Table 9) can be attributed to a large extent to household participation in agrobiodiversity enhancement project, compared to non participating households, which reflects the impact of the project on rural livelihoods. The annual increase, on average, was estimated at US$1616 per household in the four countries; and the values of Gini coefficients, a measurement of income inequality emphasis on distribution rather than tendencies, were not significantly different, indicating that enhancing agrobiodiversity did not increase inequalities between poorer and better-off farmers.

Lessons Learned

Impact assessment is a critical element of the learning process in agricultural research and development. Impact studies may primarily be initiated to answer the question 'what is the effect of research on the stated goals of the agricultural research program?' Successful impact studies often involve collection of baseline information in order to capture the situation before program interventions are made. Collection of such baseline data makes it possible for a before–after type of analysis. In this project, the baseline survey was carried out in the year 2000, focusing more on the technical and biological aspects than the socio-economic information of the target population. Information related to agrobiodiversity conservation as well as farmer's perception toward the project using a solid and extensive monitoring plan throughout the project life cycle.

Activities that help raise farmers' awareness on the importance of conserving dryland agrobiodiversity are essential. However, that alone cannot allow sustainability of the conservation actions. Hence, raising the awareness of all stakeholders is an important activity, to get, among other things, the support of government institutions in scaling up the project impacts, Any *in situ* conservation efforts will require tackling the livelihoods of the custodians of the remaining agrobiodiversity and development of enabling policies and legislations to empower local communities. The impact of this pilot project cannot be extended to more communities in the countries or outside without having a follow-up program to continue the momentum created by the project and the required support by governments within rural development programs or/and by various funds established worldwide for sharing the benefits generated from the use of genetic resources. Most farmers are keen to receive monetary incentives to contribute to conservation and sustainable use of agrobiodiversity of global importance; however, there are several other non monetary incentives that could allow intensive participation of men and women of the communities to the efforts of better management of agrobiodiversity.

The success of an agrobiodiversity conservation project not only depends on farmers' skills and knowledge but to a large extent on the overall policy environment. Policy related to agrobiodiversity conservation is part of the larger agricultural and environmental policy framework. Therefore, the policy environment has to be taken into consideration when planning, implementing and evaluating agrobiodiversity projects. As a primary task in evaluation, it is necessary to judge whether the general policy environment is conducive or hampering the implementation of projects that aim at the conservation of genetic resources. Stakeholders' involvements in planning and implementation of such projects, as well as support capacity building for national policy makers, are needed.

Since impacts are expected, it is important to follow up the project at farm level to speed up the spread of the outputs of the project and hence adoption. Many research for development projects produce research outputs, but additional actions are required to promote and disseminate the technologies or methods developed by the project.

This study also showed the importance of traditional farming systems in contributing to the on-farm conservation of dryland and mountainous agrobiodiversity. However, the sustainability of on-farm conservation of remaining agrobiodiversity will require research into low-cost technologies to improve crop and livestock productivities, the empowerment of local communities, in addition to diversification of incomes through value-adding technologies and alternative sources of incomes of the main custodians of local agrobiodiversity. This study has demonstrated that there are several technological, institutional, value-adding and alternative sources of income, which can contribute to on-farm conservation of agrobiodiversity of local and global importance.

Conclusion and Recommendations

The ways people make a living, and the constraints they face and opportunities they have, can strongly affect the status and management of their resources, including agrobiodiversity. Livelihood strategies in dry areas are dynamic, particularly due to uncertainty in agriculture driven by variation in rainfall intensity and distribution. Therefore, people engage in different livelihood activities and are always looking for additional income sources. Farmers in dry areas and the agrobiodiversity they hold face both environmental and socio-economic conditions that make the incidence of poverty relatively high.

The analysis indicated that farm resources, including water, land, livestock, agrobiodiversity, crops and knowledge, were essential resources and assets in generating livelihoods of families in the target areas. Although agriculture may not be the main source of household income, it is still a major component in dry areas. Access, control and management of these resources help shape which activities are pursued. When access is limited or opportunistic due to lack of institutions supporting this access by individuals, the ability to sustain the natural resource base and other human assets is endangered.

Data analysis also indicated that the average income from agriculture was higher for households that participated in the project than for those that did not. The estimated increase in annual household income attributed to household contribution in the project could also reflect impact of the project on rural livelihoods. The average estimated annual increase was US$1616 per household in the four countries, and ranged from US$1148 in Syria to US$1914 in Lebanon.

The results of this study highlighted the importance of agrobiodiversity conservation in improving the livelihoods of all segments of farming communities. However, to be effective, research should be based on the importance of targeted species for different farming groups. This study provides clear indications that the diversification of farming systems including livestock, field crops and fruit trees along with off-farm activities are essential for conservation and sustainable use of dryland agrobiodiversity.

Finally, to promote on-farm community-driven agrobiodiversity conservation and sustainable use for food and agriculture we recommend, at the community level, the following: (1) support on-farm conservation of agricultural biodiversity using incentives appropriate to the context; (2) support farmer-to-farmer seed exchange, including seed fairs and community seed banks, where it is effective; (3) enhance local-level seed production by providing technical backup and business advice; (4) promote integrated crop management; (5) commit to continuing natural resources research on agricultural biodiversity; (6) strengthen local community organizations to increase farmers' voices on agricultural biodiversity issues; (7) promote income-generating activities that use agricultural biodiversity; (8) strengthen local-level capacity for agricultural biodiversity management and use, including tools such as 'farmer field schools'; and (9) invest in developing local markets for biodiversity-friendly agricultural products.

The recommendations at the national level should cover: support to rural development in areas rich in agrobiodiversity, mainstreaming and better coordination of national genetic resources policies and programs, including wider stakeholder involvement in planning and implementation, and capacity building for national policy makers; and support the decentralization of agricultural research and extension services, including participatory plant breeding.

At the international level, equitable benefit sharing should target those farmers contributing to agrobiodiversity of global significance, including exchange of technologies, marketing of local products and joining efforts with national government to support rural development.

Acknowledgements. The authors thank national project managers Dr Mohamed Ajlouni (Jordan), Drs Raghed Assi and Wafa Khoury (Lebanon), Mr Younis Sbeih (Palestine) and Mr Ali Khnifes and Mr Adnan Saad (Syria) and national project socio-economic teams for facilitating the acquisition of data and the fieldwork related to promoting value-adding technologies and alternative sources of income.

References

1 CBD (Convention on Biological Diversity). 1992. Convention on Biological Diversity: Text and Annexes. CBD Secretariat, Montreal, Canada.

2 Vavilov, N.I. 1926. Studies on the origin of cultivated plants. Bulletin of Applied Botany, Genetics and Plant Breeding 16:1–248.
3 Hawkes, J.G. 1991. International workshop on dynamic *in situ* conservation of wild relatives of major cultivated plants: Summary of final discussion and recommendations. Israel Journal of Botany 40:529–536.
4 Harlan, J.R. 1992. Crops and Man. American Society of Agronomy Inc., Madison, Wisconsin, USA.
5 Maxted, N., Ford-Lloyd, B.V., and Hawkes, J.G. 1997. Complementary conservation strategies. In N. Maxted, B.V. Ford-Lloyd, and J.G. Hawkes (eds). Plant Genetic Conservation: The *In Situ* Approach. Chapman & Hall, London. p. 20–55.
6 Amri, A., Shideed, K., Mazid, A., and Valkoun, J. 2006. Agrobiodiversity conservation and the livelihoods of local communities in the dry areas of West Asia. In M.C. Saxena (ed.). The Eighth International Conference on Dryland Development. Abstracts of Papers Presented; 25–28 February 2006, Beijing, China. ICARDA, Aleppo, Syria.
7 United Nations. 2000. Agenda 21. Available at Web site http://www.un.org/esa/dsd/agenda21/
8 United Nations. 2001. Millennium Development Goals. Available at Web site http://www.un.org/millenniumgoals/index.shtml (accessed June 26, 2013).
9 FAO (Food and Agriculture Organization of the United Nations). 2001. International Treaty on Plant Genetic Resources for Food and Agriculture. FAO, Rome.
10 Jarvis, D. and Hodgkin, T. 2000. Farmer decision making and genetic diversity: Linking multidisciplinary research to implementation on-farm. In S.B. Brush (ed.). Genes in the Field: On-Farm Conservation of Crop Diversity. Lewis Publishers, Boca Raton, FL, USA. p. 261–278.
11 Jarvis, D. 1999. Strengthening the scientific basis of *in situ* conservation of agricultural biodiversity on-farm. Botanical Lithuania Suppl. 2:79–90.
12 Eyzaguirre, P. and Iwanaga, M. 1996. Farmer's contribution to maintaining genetic diversity in crops, and its role within the total genetic resources system. In P. Eyzaguirre, and M. Iwanaga (eds). Proceedings of a Workshop on Participatory Plant Breeding. IPGRI, Rome. p. 9–18.
13 Mazid, A., Shideed, K., and Amri, A. 2008. Status of and Threats to On-Farm Agrobiodiversity and its Impact on Rural Livelihoods in Dry Areas of West Asia. ICARDA, Aleppo, Syria.
14 Mainka, S.A. and Trivedi, M. (eds). 2002. Links between Biodiversity Conservation, Livelihoods and Food Security: The sustainable use of wild species for meat. IUCN, Gland, Switzerland and Cambridge, UK. vi + 135pp.
15 Carletto, G., Covarrubias, K., Davis, B., Krausova, M., Stamoulis, K.G., Winters, P.C., and Zezza, A. 2007. Rural income generating activities in developing countries: Re-assessing the evidence. Electronic Journal of Agricultural and Development Economics 31(4): 146–193. Available at Web site ftp://ftp.fao.org/docrep/fao/010/ai195e/ai195e00.pdf (accessed June 26, 2013).
16 Collinson, M.P. 1982. Farming Systems Research in Eastern Africa: The Experience of CIMMYT and some National Agricultural Research Services, 1976–81. MSU International Development Paper no. 3, Michigan, USA.
17 Bond, I., Grieg-Gran, M., Wertz-Kanounnikoff, S., Hazlewood, P., Wunder, S., and Angelsen, A. 2009. Incentives to sustain forest ecosystem services: A review and lessons for REDD. Natural Resource Issues No. 16. International Institute for Environment and Development, London, UK, with Center for International Forestry Research (CIFOR), Bogor, Indonesia, and World Resources Institute, Washington DC, USA. Available at Web site http://pubs.iied.org/pdfs/13555IIED.pdf (accessed June 26, 2013).
18 Cavendish, W. 1999. Incomes and Poverty in Rural Zimbabwe During Adjustment: The Case of Shindi Ward, Chivi Communal Area, 1993/94 to 1996/97. Rep/99-1. Centre for the Study of African Economies, University of Oxford, UK.
19 Campbel, B.M., Jeffrey, S., Kozanayi, W., Luckert, M., Mutambo, M., and Zindi, C. 2002. Household Livelihoods in Semi-Arid Regions: Options and Constraints. CIFOR, Jakarta.
20 Ellis, F. 1998. Household strategies and rural livelihood diversification. Journal of Development Studies 35:1–38.
21 Reardon, T., Delgado, C., and Matlon, P. 1992. Determinants and effects of income diversification amongst farm households in Burkina Faso. Journal of Development Studies 28:264–296.
22 Bebbington, A. 1999. Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. World Development 27:2021–2044.
23 de Haan, L.J. 2000. Globalization, localization and sustainable livelihood. Sociologia Ruralis 40:339–365.
24 Kusterer, K. 1989. Small Farmer Attitudes and Aspirations. USAID Program Evaluation Discussion Paper No. 26. USAID, Washington, DC.
25 Valdivia, C. 2001. Gender, livestock assets, resource management, and food security: Lessons from the SR-CRSP. Agriculture and Human Values 18:27–39.
26 Dunn, E., Kalaitzandonakes, N., and Valdivia, C. 1996. Risk and the Impacts of Micro-enterprise Services. Assessing the Impacts of Microenterprise Services (AIMS). MSI, Washington, DC.
27 Charles-Coll, J.A. 2011. Understanding income inequality: Concept, causes and measurement. International Journal of Economics and Management Sciences 1(3):17–28.

Renewable Agriculture and Food Systems: 29(4); 378–387 doi:10.1017/S1742170513000252

Maize silage and Italian ryegrass silage as high-energy forages in organic dairy cow diets: Differences in feed intake, milk yield and quality, and nitrogen efficiency

L. Baldinger*, W. Zollitsch and W.F. Knaus

Department of Sustainable Agricultural Systems, University of Natural Resources and Life Sciences, Gregor Mendel Strasse 33, 1180 Vienna, Austria
*Corresponding author: lisa.baldinger@boku.ac.at

Accepted 25 June 2013; First published online 6 August 2013 **Research Paper**

Abstract

During the winter feeding period in organic dairy production systems in the alpine and pre-alpine regions of Austria and its neighboring countries, maize silage is an energy-rich forage that is regularly included in grass-silage-based diets to improve the energy supply of the cows. Italian ryegrass (*Lolium multiflorum* Lam.) is also a high-energy fodder grass popular as forage for dairy cows, but it is rarely cultivated in Austrian organic agriculture. The two crops differ in their cultivation demands and characteristics. Italian ryegrass establishes rapidly and may reduce the risk of soil erosion. Italian ryegrass would be a beneficial addition to crop rotation, which is an essential tool in successful organic farming. In a 15-week feeding trial, Italian ryegrass silage and maize silage were fed to 22 lactating Holstein dairy cows. Organically produced Italian ryegrass silage and maize silage were included at a rate of 40% [of dry matter (DM)] in grass-silage-based mixed basal diets. The mixed basal diets were supplemented with modest amounts of additional concentrates (2.7–3.0 kg DM day^{-1}). Owing to the higher energy content of maize silage as compared to Italian ryegrass silage, the maize diet provided more energy [6.3 MJ net energy for lactation (NEL) kg^{-1} DM] than the ryegrass diet (6.15 MJ NEL kg^{-1} DM). The protein supply of the maize diet and the ryegrass diet was intended to be equal, but in fact the protein content of the maize diet was significantly lower (122 g crude protein kg^{-1} DM) than that of the ryegrass diet (141 g kg^{-1} DM). When the maize diet was fed, feed intake, milk yield and milk protein content were significantly higher as compared to the ryegrass diet. Also, intake of crude protein was significantly lower when feeding the maize diet, and in combination with the higher milk protein yield, this enabled an efficiency of gross nitrogen (N) utilization as high as 0.304. This level of N efficiency can be considered as above average and was significantly and considerably higher than the level of 0.259 observed when the ryegrass diet was fed. Therefore, maize silage upholds its reputation as an ideal energy-rich component in grass-silage-based dairy cow diets.

Key words: Italian ryegrass, maize silage, organic, dairy cow, nitrogen efficiency

Introduction

In the alpine and pre-alpine regions of Austria and its neighboring countries, ruminant production plays a vital role in organic agriculture, mostly due to the high proportion of total farm land that is permanent grassland. In Austria, 51.2% of the utilized agricultural area is permanent grassland[1]. Owing to ruminants' ability to digest fibrous materials, dairy production systems are well suited for utilizing grassland for the production of foods. As a consequence, organic milk production is commonly based on fresh and conserved forages from permanent grassland and perennial clover–grass leys. The latter are an essential component of crop rotation, which is of particular importance in organic farming systems. In organic crop rotations, nitrogen (N)-demanding and N-fixing crops are balanced in order to optimize yields. On an organic dairy farm, sufficient forage for cows has to be produced while still maintaining soil fertility[2]. Clover–grass provides both N for the next crop in the rotation as well as forage for the dairy cows. Ley farming also prevents soil erosion and provides carbon-rich crop residues as feed for soil

© Cambridge University Press 2013

organisms. Apart from feeding forages, most Austrian farmers supplement with concentrates to improve milk yield. Common home-grown concentrates are barley and triticale, whereas in commercial concentrates, industrial by-products (e.g., bran, press cake) are used as well. Where local growing conditions allow maize production, maize silage is valued as a high-energy forage. Including it in the diet increases the supply of ruminally fermentable carbohydrates from forage and thereby improves the capture of dietary N, a precious and scarce resource in organic agriculture. Studies in which perennial ryegrass silage is replaced with maize silage have shown that increasing inclusion of maize silage positively affects dry matter (DM) intake, milk yield, and milk protein content, while milk fat concentration is either not affected or decreases[3–5].

Italian ryegrass (*Lolium multiflorum* Lam.) is a fodder grass that has been grown in northern Italy since the 12th century[6], making it the oldest fodder grass cultivated by humans. Today, Italian ryegrass can be found in temperate regions all around the world. In Austria, it can be found in natural grassland, but is rarely cultivated due to its low frost resistance, although using it for annual (or bi-annual, depending on the winter losses) leys would avoid this problem.

Among the fodder grasses, Italian ryegrass has one of the highest energy contents, and due to its favorable composition of structural carbohydrates, it is easily digestible[7]. Reports about its positive effects on the forage intake of dairy cows are frequent[8,9], and some researchers even report better feed efficiency than when feeding maize silage[10].

In Austrian areas where the cultivation of both maize and Italian ryegrass is possible, Italian ryegrass may be an alternative to forage maize, resulting in longer rotation breaks between maize and therefore a more diverse crop rotation. In areas where conditions are not optimal for maize production, Italian ryegrass might be a valuable high-energy forage in addition to the usual clover–grass. Italian ryegrass and maize differ in their cultivation demands and characteristics: whereas maize only requires an annual precipitation of 500–800 mm[11], the annual water demand of Italian ryegrass is much higher, about 900–1200 mm[12]. Both forage crops are sensitive to low temperatures: for successful cultivation of Italian ryegrass, an average annual temperature of about 8.5°C is needed[12]. Maize for silage production requires an average temperature between 10 and 15°C between May and September[11]. Italian ryegrass is either sown in fall or in spring, establishes quickly, and covers the ground effectively. Under Austrian conditions it rarely survives more than one winter. Maize is sown in April/May and harvested for silage in September/October, and especially under organic cultivation, establishment is slow. Owing to its high nutrient demand, maize is commonly planted after clover–grass or other legumes[13]. Italian ryegrass has no special demands with regard to the preceding crop, although it thrives when planted after legumes. Possible succeeding crops after Italian ryegrass are grain legumes or summer cereals[13]. Special attention must be paid to the N supply of succeeding crops, because the crop residues left behind by Italian ryegrass are rich in carbon but poor in N. Italian ryegrass itself requires regular, moderate fertilization with manure in order to realize its potential. Thus, both maize and Italian ryegrass can be considered intensive forage crops under the conditions of organic agriculture.

The objective of this study was to compare Italian ryegrass silage and maize silage as forage for dairy cows under the conditions of Austrian organic agriculture. Therefore, a feeding trial was conducted in which Italian ryegrass silage and maize silage were included in grass-silage-based mixed basal diets for dairy cows during the winter feeding period. The main questions were how intake of DM, milk yield, and quality and production efficiency, especially gross N efficiency, would differ depending on the forages used. The milk fatty acid profile was chosen as an additional parameter to describe milk quality.

Materials and Methods

Italian ryegrass harvest

Italian ryegrass (*L. multiflorum* Lam. var. *italicum*, cultivar: TIGRIS) was grown in a field belonging to the Secondary Agriculture and Forestry College at Ursprung (HLFS Ursprung) in the province of Salzburg, Austria (570 m NN, 1250 mm precipitation, 8.5°C average annual temperature). The preceding crop was clover–grass. After seeding on April 16, 2010, the first cut on May 11 was a cleaning cut due to weeds, and the second (June 24) and third cuts (July 19) were ensiled without additives as round bales. After the second and third cut, liquid manure was applied at a rate of 40 kg N (10 kg of which were NH_4-N) per hectare. The two ensiled cuts combined yielded 2.9 t DM ha^{-1}.

Experimental design and animals

The feeding trial was conducted with the organically managed HLFS Ursprung dairy herd, which is housed in a cubicle housing system equipped with Calan gates for individual feeding. Milking takes place in a 2 × 3 herringbone milking parlor twice a day, at 6:00 and 16:30. A total of 22 lactating Holstein cows were included in the feeding trial between November 2010 and February 2011, but only 19 cows were included for the whole trial. The remaining three cows were included belatedly because of delayed calving or were eliminated prematurely because they were dried off. At the beginning of the experiment, the cows were divided into two treatment groups of 11 cows each, based on number of lactation (2.5 ± 1.7 versus 3.0 ± 1.5), days in milk (110 ± 65 versus 141 ± 109),

Table 1. Nutrient content and fermentation traits of silages, g kg^{-1} DM unless stated otherwise.

			Italian ryegrass silage				
	Grass silage $n=2$	Maize silage $n=2$	2nd cut $n=2$	3rd cut $n=2$	Hay $n=2$	Barley $n=2$	Soybean cake $n=2$
Nutrients							
DM (g kg^{-1} fresh weight)	338	388	356	225	942	867	921
Crude protein	99	75	160	118	85	123	460
uCP	130	133	136	121	115	162	299
Ether extracts	28	31	40	38	24	26	93
NDF	426	403	491	527	646	.	.
ADF	243	219	282	309	382	.	.
Lignin (sa)	31	31	49	45	63	.	.
Starch	.	375	.	.	.	533	87
Sugar	21	9	23	13	146	.	108
Ash	98	33	127	117	63	28	76
NEL (MJ kg^{-1} DM)	6.33	6.77	6.14	5.55	5.38	8.00	8.93
Fermentation traits							
pH	4.5	4.3	5.2	5.2			
Lactic acid	30.1	22.0	16.3	7.9			
Acetic acid	14.8	8.1	2.6	3.1			
Butyric acid	8.9	0.5	5.7	23.4			
Ammonia-N (g kg^{-1} of total N)	53	65	57	100			

DM, dry matter; uCP, utilizable crude protein at the duodenum; NDF, neutral detergent fiber; ADF, acid detergent fiber; and NEL, net energy lactation.

milk yield (27.4 ± 9.5 versus 23.9 ± 5.1 kg), and live weight (654 ± 62 versus 665 ± 47 kg). After an initial 3-week adaptation period to the Calan gates and the feeding regimen, data were collected over 12 weeks. Treatments were switched after week 6 to ensure that every cow received every treatment. The feeding trial was conducted according to the EU Directive 2010/63/EU for animal experiments[14] and the Austrian Act on Animal Experiments[15]. No invasive procedures were performed on the cows.

Feeding regimen

Two mixed basal diets based on grass silage and hay and supplemented with additional concentrates were compared. The nutrient content and fermentation traits of the feeds included in mixed basal diets are summarized in Table 1. Grass silage consisted of a mixture of a first cut from permanent grassland and a third cut from a perennial clover–grass ley in its third year; therefore, clover proportion was already low. Hay was produced from a first cut of permanent grassland, and residual drying was performed in the barn by a ventilation system. Owing to a crop failure at HLFS Ursprung, maize silage produced according to the regulations of Austrian organic agriculture was purchased from a farmer in the Austrian province Lower Austria. The DM content of the silages ranged between 338 and 388 g kg^{-1} fresh matter, except for the third cut of Italian ryegrass, which was poorly fermented and numerically lower in energy and DM (225 g kg^{-1} fresh weight) than the other silages. The crude protein content of the silages varied greatly, from as low as 75 g kg^{-1} DM in the maize silage to 99 g kg^{-1} DM in the grass silage, and up to 160 g kg^{-1} DM in the ensiled second cut of Italian ryegrass.

Table 2 shows the ingredients and nutrient content of the mixed basal diets. Considerable amounts of maize silage and Italian ryegrass were included in diet M (maize diet) and diet R (ryegrass diet), respectively, to make the effects of and differences between the two forages clearly visible. In order to avoid the negative effects of protein deficiency in the maize diet, differing amounts of barley and soybean cake were added to the forages. The resulting mixed basal diets were meant to be isonitrogenous with a calculated crude protein content of 142 g kg^{-1} DM, but not isoenergetic. However, in fact, the crude protein content of mixed basal diet R turned out to be significantly higher than in mixed basal diet M. Regarding the content of utilizable crude protein at the duodenum (uCP), which is influenced by the energy content of the feed, the reverse was true. Regarding carbohydrate composition, only neutral detergent fiber (NDF) content was significantly higher in mixed basal diet R, whereas starch content was considerably and significantly higher in mixed basal diet M. Owing to the third cut of Italian ryegrass silage being considerably wetter than the other silages, mixed basal diet R had a significantly lower content of DM than mixed basal diet M.

The mixed basal diets were prepared daily and offered twice a day in amounts to ensure feed refusals of 5–10%.

Table 2. Ingredients and nutrient content of mixed basal diets, g kg^{-1} DM unless stated otherwise.

	Mixed basal diet		R^2	*P* value
	Maize *n*=8	Ryegrass *n*=8		
Ingredients				
Grass silage	380	380		
Maize silage	400	–		
Italian ryegrass silage, 2nd cut	–	200		
Italian ryegrass silage, 3rd cut	–	200		
Hay	100	100		
Barley	20	100		
Soybean cake	100	20		
Nutrients				
DM (g kg^{-1} fresh weight)	370	352	0.29	**0.032**
Crude protein	122	141	0.60	**<0.001**
uCP	136	133	0.27	**0.041**
Ether extracts	31	32	0.35	**0.015**
NDF	449	468	0.33	**0.020**
ADF	267	287	0.24	0.055
Lignin (sa)	50	51	0.00	0.962
Starch	183	44	0.95	**0.027**
Sugar	35	41	0.73	0.143
Ash	82	110	0.82	**<0.001**
NEL (MJ kg^{-1} DM)	6.30	6.15	0.37	**0.012**

DM, dry matter; uCP, utilizable crude protein at the duodenum; NDF, neutral detergent fiber; ADF, acid detergent fiber; NEL, net energy lactation.

The herd included cows in different stages of lactation and therefore a wide range of milk yields. In order to enable cows to maintain their production level, additional concentrates were supplemented according to milk yield: Cows exceeding a daily milk yield of 15 kg received a commercial concentrate mixture (166 g crude protein, 7.79 MJ net energy for lactation (NEL) kg^{-1} DM; $n=2$) at a rate of 0.5 kg DM for each additional kg of milk yield, up to a maximum of 6 kg DM concentrates. Concentrates were fed via an automatic feeding station, and quantities were adjusted weekly. Furthermore, all cows received 50 g of a commercial mineral and vitamin mixture per day.

Data collection and analytical procedures

Throughout the experiment, milk yield and intake of additional concentrates were documented continuously, while individual intake of mixed basal diets was recorded manually only during four 6-day recording periods in weeks 3, 6, 9 and 12. For feed analysis, the following samples (each pooled over two consecutive days) were taken for each recording period: one sample of each dietary component (only during weeks 3 and 9), two samples of both freshly mixed basal diets, and one sample of each treatment's feed refusals. The feed samples were analyzed according to the German Handbook of Agricultural Experimental and Analytical Methods[16] and method numbers are given. The DM content of feed offered and feed refusals was determined by oven-drying at 105°C (3.1). Ash, ether extracts, and sugar and starch content were analyzed using methods 8.1, 5.1.1, 7.1.1, and 7.2.1, respectively. Content of crude protein was assayed with Dumas combustion (4.1.2). NDF (6.5.1) in grass and ryegrass silages was determined without a heat stable amylase, while for analysis in maize silage and mixed basal diets alpha-amylase was added. Both NDF and acid detergent fiber (ADF, 6.5.2) are expressed inclusive of residual ash. Lignin was determined by solubilization of cellulose with sulfuric acid (6.5.3). Content of NEL and utilizable crude protein at the duodenum (uCP[17]) were calculated according to GfE[18].

A total of 16 milk samples (each pooled over two consecutive milkings) per cow were taken and conserved with Bronopol® until analysis for fat, protein, lactose and urea concentrations were conducted. An additional set of individual milk samples from the 19 cows that were included in the whole trial was taken for analysis of milk fatty acid profile during weeks 6 and 12. These samples were stored at −20°C until gas chromatographic analysis of fatty acid composition was performed at the laboratory and quality service center Muva, Kempten, Germany. Once a week, cows' live weights were determined by weighing them twice immediately after milking and calculating the mean. Nutrient balances and efficiency calculations were computed according to GfE[18].

Statistical analysis

For statistical analysis, the program package SAS[19] was used. The nutrient content of the mixed basal diets was analyzed using proc GLM, with a model including only the fixed effect of treatment. All other data were analyzed using proc MIXED, using the following model:

$$Y_{klmnopqr} = \mu + \text{treatment}_k + \text{day}_l + \text{order}_m + \text{LN}_n + \text{LS}_o + \text{ECM}_p + \text{LW}_q + \text{treatment} \times \text{LN} + \text{treatment} \times \text{LS} + \text{cow(order)}_{rm} + \varepsilon_{klmnopqrs}$$

where Y = variable studied; μ = overall mean; treatment = fixed effect of treatment k (M, R); day = fixed effect of day l in the feeding trial (1, 2, ..., 83); order = fixed effect of order m (1, 2); LN = fixed effect of number of lactation n (1,2, ..., 6); LS = fixed effect of stage of lactation o, expressed as thirds (1st and 2nd 100 days, >200 days in milk); ECM = continuous effect of daily ECM yield p of cow r (only for parameters of feed intake); LW = continuous effect of live weight q of cow r (only for parameters of feed intake and milk fat, protein and lactose content); treatment × LN = interaction between treatment k and lactation number n; treatment × LS = interaction between treatment k and stage of lactation o; cow(order) = random effect of cow r within order m; ε = random error.

Table 3. Daily intake of DM, nutrients and energy of organically managed dairy cows fed diets containing either maize silage or Italian ryegrass silage.

	Treatment				
	Maize	**Ryegrass**	**SD**	***P* value**	**CovS**
DM (kg)					
Mixed basal diet	15.3	14.2	1.51	**<0.001**[1]	SP(POW)
Concentrate	3.0	2.7	1.73	**0.007**	SP(POW)
Total	18.4	17.0	1.58	**<0.001**	SP(POW)
Nutrients (g)					
Crude protein	2380	2459	241.3	**0.017**	SP(POW)
uCP	2598	2364	231.7	**<0.001**	SP(POW)
Ether extracts	591	566	55.3	**<0.001**	SP(POW)
NDF from mixed basal diet	6968	6738	746.5	**0.002**	SP(POW)
ADF from mixed basal diet	4108	4134	468.0	0.635	SP(POW)
Lignin(sa) from mixed basal diet	686	708	180.0	**0.018**	CSH
Energy, MJ NEL	120	109	10.7	**<0.001**	SP(POW)

uCP, utilizable crude protein at the duodenum; NDF, neutral detergent fiber;
ADF, acid detergent fiber; NEL, net energy lactation.
CovS, covariance structure: CSH, heterogeneous compound symmetry; SP(POW), spatial power law.
[1] *P* value of interaction treatment × number of lactations = 0.008.

Except for the main effects of treatment and day, fixed effects and interactions which were not statistically significant were excluded from the individual models. This did not result in any changes in the interpretation of results. Tables 3 and 4 include information on significant interactions, which have a marked influence on the interpretation of results. Seven covariance structures possibly suitable for the data at hand were tested: unstructured (UN), antedependence (ANTE[1]), compound symmetry (CS), heterogeneous compound symmetry (CSH), spatial power law (SP[POW]), spatial Gaussian (SP[GAU]), and spatial spherical (SP[SPH]). The covariance structure with the Bayesian information criterion value closest to zero, which indicates the best fit of the model to the data, was selected[20]. For analysis of milk fatty acids, only the covariance structure CS was used. Statistical differences were considered to be significant when $P < 0.05$. Table 1 shows the arithmetic means of the nutrients content and fermentation traits of the feeds, Table 2 shows the least-squares means of the nutrient content of mixed basal diets, the pertaining probability values (*P* value) and the coefficients of determination (R^2). Tables 3–5 show least-squares means for treatment, the residual standard deviation (SD), the *P* values, and the covariance structure used (CovS).

Results

Feed and nutrient intake

Feeding the maize diet resulted in a significantly higher intake of mixed basal diet (+1.1 kg DM) and also of total energy (+11 MJ NEL, see Table 3). Even though a significant interaction between treatment and number of lactation was observed, treatment M led to an increase in every lactation. Feeding the ryegrass diet significantly increased crude protein intake by 3.3%, but due to the significantly higher energy content of mixed basal diet M, intake of uCP was 10% higher when feeding the maize diet. Although the mixed basal diet R contained significantly more NDF than the mixed basal diet M, intake of NDF was significantly higher (+3.4%) in treatment M due to the resulting higher intake of DM. Lignin determined by solubilization of cellulose with sulfuric acid [Lignin (sa)] intake was 3.2% higher in cows fed the ryegrass diet, whereas intake of ether extracts was significantly higher (+4.4%) in treatment M.

Milk production, nutrient balances, and feed efficiency

Feeding the maize diet significantly increased milk yield (+2.3 kg) as well as milk protein content (+1.2 g kg^{-1}), whereas milk fat content was significantly lower (2.9 g kg^{-1}, see Table 4). Despite lower milk fat content, both milk fat yield (+13.2%) and milk protein yield (+17.2%) were significantly higher in treatment M. Milk urea content was significantly lower when the maize diet was fed. Even though significant interactions between treatment and number of lactation and treatment and stage of lactation were observed, feeding the maize diet always decreased milk urea content. On average, cows fed the maize diet produced milk with a urea content of 78 mg l^{-1}, whereas cows fed the ryegrass diet had a milk urea content of 137 mg l^{-1}.

Nutrient balances and calculated parameters of production efficiency are given in Table 4. The uCP and NEL balances were positive in both treatments, but only NEL

Table 4. Milk production traits, nutrient balances and efficiency of milk production of organically managed dairy cows fed diets containing either maize silage or Italian ryegrass silage.

	Treatment				
	Maize	Ryegrass	SD	*P* value	CovS
Milk production					
Milk yield (kg)	22.7	20.4	5.72	**<0.001**	SP(POW)
ECM (kg)	23.3	21.3	7.03	**<0.001**	CSH
Fat content (g kg^{-1})	40.8	43.7	6.61	**<0.001**	SP(POW)
Protein content (g kg^{-1})	33.0	31.8	2.61	**<0.001**	CSH
Lactose content (g kg^{-1})	47.0	47.2	1.92	0.198[1]	CSH
Urea content (mg l^{-1})	78.1	137.0	28.4	**<0.001**[2]	SP(POW)
Fat yield (g)	970	857	256.3	**<0.001**	SP(POW)
Protein yield (g)	737	629	155.2	**<0.001**	SP(POW)
Nutrient balances					
Ruminal N balance (g)	−29.4	9.4	12.45	**<0.001**	ANTE(1)
uCP balance (%)	119	120	13.2	0.512	SP(POW)
Live weight change (kg day^{-1})	0.20	0.10	1.403	0.509	SP(POW)
NEL balance (%)	109	104	10.9	**<0.001**	SP(POW)
Efficiency of milk production					
Feed efficiency[3]	1.23	1.19	0.210	0.486	SP(SPH)
Gross N efficiency[4]	0.304	0.259	0.0457	**<0.001**	SP(POW)

ECM, energy corrected milk; uCP, utilizable crude protein at the duodenum;
NEL, net energy lactation; N, nitrogen;
CovS, covariance structure: ANTE(1), first-order antedependence structure;
CSH, heterogenous compound symmetry; SP(POW), spatial power law; SP(SPH), spatial spherical.
[1] *P* value of interaction treatment × stage of lactation = 0.004.
[2] *P* value of interaction treatment × stage of lactation = 0.002 and treatment × number of lactation = 0.005.
[3] g ECM kg^{-1} total intake of DM.
[4] g N milk kg^{-1} N consumed.

balance was significantly higher (+5 percentage points) in treatment M. Live weight change was slightly positive as well and did not differ. Ruminal N balance was significantly lower when the maize diet was fed. Feeding the ryegrass diet resulted in a gross N efficiency of 0.259, whereas feeding the maize diet resulted in a significantly higher gross N efficiency of 0.304.

Milk fatty acid profile

The effect of dietary treatment on milk fatty acid profile is summarized in Table 5. Of the main milk fatty acids palmitic, stearic, oleic and myristic acids, which together comprised approximately 700 g kg^{-1} total fat, only palmitic and myristic acids were affected by treatment. While myristic acid was significantly higher when the maize diet was fed, palmitic acid was significantly lower. Feeding the maize diet also resulted in a higher proportion of the *de novo* fatty acids C8:0-C14:0, as well as a higher proportion of linoleic acid, $n-6$ fatty acids and consequently a higher $n-6/n-3$ ratio. Proportions of vaccenic and rumenic acid and the sum of trans fatty acids were higher when the ryegrass diet was fed. Despite these differences in individual milk fatty acids, neither saturated fatty acids (SFA) nor mono-unsaturated fatty acid (MUFA) were influenced by treatment, only the poly-unsaturated fatty acids (PUFA) content was significantly increased when the maize diet was fed.

Discussion

This study was conducted to compare maize silage and Italian ryegrass silage as forage components in mixed basal diets for dairy cows under the conditions of Austrian organic agriculture. Despite the addition of adjusted amounts of barley and soybean cake to achieve isonitrogenous mixed basal diets, crude protein content was significantly higher in mixed basal diet R (including Italian ryegrass silage), while contents of uCP were slightly, but significantly higher in mixed basal diet M (including maize silage).

Feed composition, feed and nutrient intake

The DM content, fermentation quality and energy values of the silages ranged between good and ideal, except for the third cut of Italian ryegrass (see Table 1). Ash content of all samples of both ensiled cuts of Italian ryegrass (raw data not shown) was higher than 100 g kg^{-1} DM, indicating some contamination with soil particles during harvest. However, only in the third cut did this lead to higher levels of butyric acid and degradation of protein

Table 5. Fatty acid profile and groups of fatty acids of milk fat ($g\,kg^{-1}$ total fat) of organically managed dairy cows fed diets containing either maize silage or Italian ryegrass silage.

		Treatment			
		Maize	**Ryegrass**	**SD**	***P* value**
Fatty acid					
Butyric acid	C4:0	42.6	44.3	3.62	**0.031**
Caproic acid	C6:0	24.8	24.1	10.18	0.204
Caprylic acid	C8:0	14.4	13.3	1.85	**0.006**
Capric acid	C10:0	31.0	28.0	5.25	**0.003**
Lauric acid	C12:0	35.1	31.3	5.56	**<0.001**
Myristic acid	C14:0	116	111	6.2	**0.008**
Palmitic acid	C16:0	313	332	34.1	**0.002**
Stearic acid	C18:0	95.7	91.5	14.68	0.358
Arachidic acid	C20:0	1.5	1.5	0.21	0.694
Behenic acid	C22:0	0.46	0.51	0.101	0.066
Oleic acid	C18:1 c9	182	178	25.3	0.246
Vaccenic acid	C18:1 t11	13.9	19.3	3.53	**<0.001**
Linoleic acid	C18:2 c9c12	14.8	11.6	2.68	**<0.001**
Rumenic acid	C18:2 c9t11	6.0	8.4	2.14	**<0.001**
α-linolenic acid	C18:3c9c12c15	4.8	5.5	1.05	**0.011**
γ-linolenic acid	C18:3 c6c9c12	0.35	0.32	0.162	0.384
Fatty acid groups					
SFA		698	696	33.6	0.688
MUFA		221	215	29.8	0.121
PUFA		23.5	21.1	2.78	**<0.001**
trans fatty acids		34.5	39.4	5.87	**<0.001**
$n-3$ fatty acids		6.8	7.5	1.19	**0.009**
$n-6$ fatty acids		17.0	13.5	2.78	**<0.001**
$n-6/n-3$ ratio		2.52	1.84	0.233	**<0.001**

SFA, saturated fatty acids; MUFA, mono-unsaturated fatty acids; PUFA, poly-unsaturated fatty acids.

to ammonia-N, probably due to the fact that the butyric-acid-producing clostridia prefer wet conditions[21]. The unusually low crude protein content of grass silage probably resulted from low amounts of clover in the grass-clover leys that provided part of the substrate.

The general level of intake of DM (17.0–18.4 kg, see Table 3) is in accordance with the average of 18.5 kg (13.0 kg forage plus 5.5 kg concentrates) observed by Gruber et al.[22] based on the analysis of an extensive database of 2151 lactating dairy cows. Important factors influencing forage intake are DM and energy content, and fermentation quality of the forage[23,24]. The ryegrass diet had the disadvantage of containing a wet, suboptimally fermented and low-energy third cut of Italian ryegrass, and consequently almost all parameters of feed intake were improved when the maize diet was fed. However, even the energy content of the well-preserved second cut of Italian ryegrass was numerically lower than the maize silage, therefore, the ryegrass diet would have had a lower energy content than the maize diet even without the added disadvantage of the suboptimally fermented third cut. When substituting parts of a maize-silage-based diet ($312\,g\ DM\ kg^{-1}$) with Italian ryegrass silage ($264\,g\ DM\ kg^{-1}$), Cooke et al.[25] found a significant positive relationship between the proportion of maize silage and intake of DM, which is in accordance with the findings of the present study. However, Bernard et al.[9] report quite the reverse. In this study, cows showed numerically but not significantly, higher intakes of DM when Italian ryegrass was the sole forage as compared to maize silage (44.5% concentrates of total feed DM).

Milk yield and composition

There are frequent reports of a positive correlation between starch intake and milk yield, while milk fat content decreases[26–28]. Since the maize diet contained significantly more starch than the ryegrass diet, the difference in starch intake explains the higher milk yield and lower milk fat content when the maize diet was fed. Feeding trials comparing maize silage and Italian ryegrass silage as forage for high-yielding dairy cows (44–54% concentrates of total feed DM) do not give a consistent picture of the effect on milk yield. Neither Calabro et al.[29] nor Cooke et al.[10,25] report an effect when comparing Italian ryegrass silage as the sole forage to a mixture with maize silage, and when comparing total mixed rations with maize silage or Italian ryegrass silage, respectively. Bernard et al.[9], however, report higher intake of DM as well as higher milk yield when feeding Italian ryegrass silage as the sole

forage. Apart from severe undersupply with energy, milk lactose content is hardly ever influenced by feeding[30]; therefore, the lack of treatment effect on milk lactose content was to be expected.

Some of the most important dietary factors influencing milk fatty acid composition are fat intake, energy balance and proportion of starch in the diet.

Intake of ether extracts was significantly higher in treatment M. Although not measured in this experiment and although variation in the content of individual fatty acids is considerable, maize oil is generally higher in linoleic acid and lower in alpha-linolenic acid than grass silage[31]. As a result, cows fed the maize diet produced milk with significantly higher content of linoleic acid, $n-6$ fatty acids in general, and consequently a higher $n-6/\ n-3$ ratio. On the other hand, milk from cows fed the ryegrass diet contained significantly higher proportions of trans fatty acids in general and of vaccenic and rumenic acid specifically. Vaccenic and rumenic acid are intermediates of the biohydrogenation of dietary alpha-linolenic and linoleic acids in the rumen, and as the major conjugated linoleic acid isomers in milk fat they seem to be associated with positive effects on human health[32]. The $n-6/\ n-3$ ratio of 1.84 observed in treatment R is in accordance with levels reported by Fall and Emanuelson[33] for organically managed dairy cows during the indoor season, whereas the ratio of 2.52 observed in treatment M is considerably higher. In general, a lower ratio of $n-6/\ n-3$ fatty acids is more desirable for human consumption, but still the milk produced from all cows was well below the recommendations (5:1) given by DACH[34].

According to Walker et al.[28], the higher proportion of *de novo* fatty acids observed when the maize diet was fed can be explained by the fact that both energy intake and energy balance were significantly higher in treatment M. When substituting increasing parts of a grass silage based diet with maize silage, Kliem et al.[5] found an increasing proportion of *de novo* fatty acids as well. Usually, increasing starch intake at the expense of fiber is known to result in higher ruminal propionate and less acetate production. However, the slowly degradable starch in maize has also been shown to increase ruminal butyrate production[35], which, together with acetate, is a precursor of the *de novo* synthesized milk fatty acids. Therefore, the higher starch intake when the maize diet was fed had a positive effect on the proportion of the short and middle-chain fatty acids C8:0–C14:0. Also, both diets were based on grass silage and hay and therefore fiber was not a limiting factor. A higher proportion of myristic acid, but lower proportion of palmitic acid in milk fat when feeding maize silage has also been found by Nielsen et al.[27] who compared maize silage and grass silage as the sole forage for dairy cows. To summarize, even though the milk fatty acid profile showed some beneficial characteristics when the ryegrass diet was fed, the overall differences were small and are not expected to substantially influence human health.

Nutrient balances and efficiency of milk production

Positive nutrient balances and live weight change indicate an adequate supply of uCP and energy for all cows (see Table 4). Cows fed the maize diet had higher uCP intakes but also higher milk protein yields, therefore no difference in uCP balance was observed. Unlike uCP balance both ruminal N balance and milk urea content were significantly lower in treatment M; while the ruminal N balance observed in treatment R (9.4 g) indicates an adequate protein supply, the negative value of −29.4 g found in treatment M can be interpreted as a protein undersupply to ruminal microbes, according to the recommendations of GfE[18]. Milk urea content is used as a tool to monitor protein nutrition of dairy cows, because it reflects the N surplus for microbial synthesis in the rumen[36]. Nousiainen et al.[37] even report an adequate protein supply to microbes only at 251 mg l^{-1} milk urea content, without regarding N-recycling via the ruminohepatic circle. Compared to these results, the values measured in the experiment in question indicate that the protein supply to ruminal microbes was scarce when the ryegrass diet was fed (average milk urea content 137 mg l^{-1}), and very scarce when the maize diet was fed (average milk urea content 78 mg l^{-1}). When dairy cows are not adequately supplied with protein, at least part of the protein deficit can be mobilized from body tissue, before milk yield eventually starts to decline[38,39]. However, the fact that the protein-scarce maize diet resulted in significantly higher milk yields and did not cause negative live weight changes allows for the conclusion that scarce protein supply to the ruminal microbes did not (yet) harm the cows and their performance.

The observed feed efficiencies of 1.19–1.23 kg ECM kg^{-1} intake of DM lie within the range of previous reports about organically managed dairy cows, ranging from 1.11 kg milk kg^{-1} intake of DM when only 1.3 kg DM of concentrates were supplemented[40] (forage base consisted of grass–clover silage and maize silage) to 1.35–1.37 kg ECM kg^{-1} intake of DM when 10 kg DM of concentrates were supplemented[41] (forage base grass–clover silage). The gross N efficiency of 0.259 observed when feeding the ryegrass diet is similar to the level of 0.255 observed by Velik et al.[42] (forage-base grass–clover silage, supplemented with 3 kg DM of concentrates), but at the lower end of the range of 0.25–0.30 that according to Chase[43] can be considered as average, while the level of 0.304 achieved with the maize diet is already slightly above average. Although the biological potential of cows to convert feed N into milk N is limited, N efficiency can be improved by reducing feed N intake and thereby optimizing the use of microbial protein synthesis in the rumen[44]. Accordingly, the positive effect of the maize diet can be attributed to the fact that cows fed the maize diet had a lower intake of crude protein but a higher milk protein yield than cows fed the ryegrass diet. A positive

effect of including maize silage in grass-silage-based diets on N efficiency has also been found by Givens and Rulquin[45], who reviewed numerous feeding trials. They attributed the effect to a better energy supply to the ruminal microbes and therefore enhanced synthesis of microbial protein, whereas in the experiment in question the effect of lower crude protein intake might have been more important.

Conclusions

Including maize silage at a rate of 40% (of DM) in a grass-silage-based diet for dairy cows and the conditions of Austrian organic agriculture was found to result in a significantly higher intake of DM and milk yield than including Italian ryegrass silage. The significantly lower intake of crude protein when feeding the maize diet as compared to the ryegrass diet, in combination with a higher milk protein yield, enabled an efficiency of gross N utilization as high as 0.304 when the maize diet was fed. This was significantly and considerably higher than the level of 0.259 observed when the ryegrass diet was fed. Therefore, maize silage upholds its reputation as an ideal energy-rich component in grass-silage-based dairy cow diets, and as long as it can be easily incorporated into crop rotation, its cultivation is recommended.

Acknowledgements. Funding of this research project was provided by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, Bio Austria, the Salzburger Landesregierung and Raiffeisenverband Salzburg. Furthermore, the authors want to thank the Secondary Agriculture and Forestry College at Ursprung for housing the experiment, the farm staff for their help with the experimental work, the laboratory and quality service center Muva Kempten, Germany, for analysis of milk fatty acids and Kathleen Knaus for editing assistance.

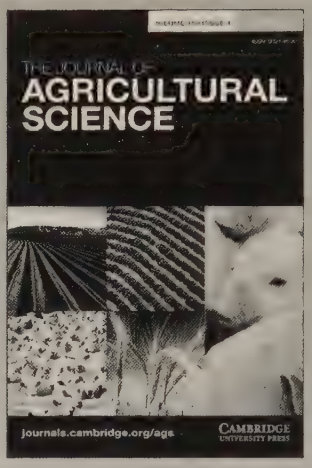
References

1 Statistik Austria. 2010. Agrarstrukturerhebung 2010 [Agricultural Structure Survey 2010]. Self-publishing, Vienna, Austria. p. 33.
2 Weller, R.F. and Bowling, P.J. 2007. The importance of nutrient balance, cropping strategy and quality of dairy cow diets in sustainable organic systems. Journal of the Science of Food and Agriculture 87:2768–2773.
3 Burke, F., Murphy, J.J., O'Donovan, M.A., O'Mara, F.P., Kavanagh, S., and Mulligan, F.J. 2007. Comparative evaluation of alternative forages to grass silage in the diet of early lactation dairy cows. Journal of Dairy Science 90:908–917.
4 Keady, T.W.J., Kilpatrick, D.J., Mayne, C.S., and Gordon, F.J. 2008. Effects of replacing grass silage with maize silages, differing in maturity, on performance and potential concentrate sparing effect of dairy cows offered two feed value grass silages. Livestock Science 119:1–11.
5 Kliem, K.E., Morgan, R., Humphries, D.J., Shingfield, K.J., and Givens, D.I. 2008. Effect of replacing grass silage with maize silage in the diet on bovine milk fatty acid composition. Animal 2(12):1850–1858.
6 George, R.A.T. 2011. Agricultural Seed Production. CAB International, Wallingford, UK.
7 Tamburini, A., Rapetti, L., Crovetto, G.M., and Succi, G. 1995. Rumen degradability of dry matter, NDF and ADF in Italian ryegrass (*Lolium multiflorum*) and winter cereal silages. Zootecnica e Nutrizione Animale 21(Suppl.):75–80.
8 Baldinger, L., Baumung, R., Zollitsch, W., and Knaus, W.F. 2011. Italian ryegrass silage in winter feeding of organic dairy cows: Forage intake, milk yield and composition. Journal of the Science of Food and Agriculture 91 (3):435–442.
9 Bernard, J.K., West, J.W., and Trammell, D.S. 2002. Effect of replacing corn silage with annual ryegrass silage on nutrient digestibility, intake, and milk yield for lactating dairy cows. Journal of Dairy Science 85(9):2277–2282.
10 Cooke, K.M., Bernard, J.K., and West, J.W. 2008. Performance of dairy cows fed annual ryegrass silage and corn silage with steam-flaked or ground corn. Journal of Dairy Science 91(6):2417–2422.
11 FAO [Food and Agriculture Organization of the United Nations]. 2009. Crop Water Information: Maize. Available at Web site http://www.fao.org/nr/water/cropinfo_maize.html (verified May 21, 2013).
12 Dietl, W. and Lehmann, J. 2004. Ökologischer Wiesenbau [Organic Grassland Production]. Österreichischer Agrarverlag, Leopoldsdorf, Austria.
13 Freyer, B. 2003. Fruchtfolgen—Konventionell, Integriert, Biologisch [Crop Rotations—Conventional, Integrated, Organic]. Eugen Ulmer, Stuttgart, Germany.
14 The European Parliament and the Council of the European Union. 2010. Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes. Official Journal of the European Union 276:33–79.
15 Federal Law Gazette 198/2000 for the Austrian republic of 30 June 2000 on the Act of Animal Experiments. Available at Web site http://www.bmwf.gv.at/fileadmin/user_upload/forschung/recht/tierversuche/tvvo.pdf (accessed July 28, 2013).
16 VDLUFA [Association of German Agricultural Analytic and Research Institutes] (ed.). 1993. Handbuch der Landwirtschaftlichen Versuchs- und Untersuchungsmethodik (VDLUFA-Methodenbuch), Band III: Die chemische Untersuchung von Futtermitteln [Handbook of Agricultural Experimental and Analytical Methods, Volume III: The chemical analysis of feedstuffs]. VDLUFA-Verlag, Darmstadt, Germany.
17 Lebzien, P. and Voigt, J. 1999. Calculation of utilizable crude protein at the duodenum of cattle by two different approaches. Archives of Animal Nutrition 52(4):363–369.
18 GfE [Society of Nutrition Physiology]. 2001. Empfehlungen zur Energie- und Nährstoffversorgung der Milchkühe und Aufzuchtrinder [Recommendations on the energy and nutrient supply for dairy cows and heifers]. DLG-Verlag, Frankfurt am Main, Germany.
19 SAS. 2002. Software, Release 9.1.3. SAS Institute Inc., Cary, NC, USA.
20 Wang, Z. and Goonewardene, L.A. 2004. The use of MIXED models in the analysis of animal experiments

with repeated measures data. Canadian Journal of Animal Science 84(1):1–11.
21 Wilkinson, J.M. 2005. Silage. Chalcombe Publications, Lincoln, UK.
22 Gruber, L., Schwarz, F.J., Erdin, D., Fischer, B., Spiekers, H., Steingaß, H., Meyer, U., Chassot, A., Jilg, T., Obermaier, A., and Guggenberger, T. 2005. Prediction equations for feed intake of lactating dairy cows. Proceedings of the Society of Nutrition Physiology 14:42.
23 Huhtanen, P., Khalili, H., Nousiainen, J.I., Rinne, M., Jaakkola, S., Heikkilä, T., and Nousiainen, J. 2002. Prediction of the relative intake potential of grass silage by dairy cows. Livestock Production Science 73(2–3):111–130.
24 Krizsan, S.J., Westad, F., Ådnøy, T., Odden, E., Aakre, S.E., and Randby, Å.T. 2007. Effect of volatile compounds in grass silage on voluntary intake by growing cattle. Animal 1(2):283–292.
25 Cooke, K.M., Bernard, J.K., and West, J.W. 2009. Performance of lactating dairy cows fed ryegrass silage and corn silage with ground corn, steam-flaked corn, or hominy feed. Journal of Dairy Science 92(3):1117–1123.
26 Murphy, J.J. and O´Mara, F. 1993. Nutritional manipulation of milk protein concentration and its impact on the dairy industry. Livestock Production Science 35(1–2):117–134.
27 Nielsen, T.S., Straarup, E.M., Vestergaard, M., and Sejrsen, K. 2006. Effect of silage type and concentrate level on conjugated linoleic acids, trans-C18:1 isomers and fat content in milk from dairy cows. Reproduction Nutrition Development 46(6):699–712.
28 Walker, G.P., Dunshea, F.R., and Doyle, P.T. 2004. Effects of nutrition and management on the production and composition of milk fat and protein: A review. Australian Journal of Agricultural Research 55(10):1009–1028.
29 Calabro, S., Caligiuri, A., Piccolo, V., and Infascelli, F. 2004. Insilato di loiessa e silomais nell'alimentazione della vacca [Italian ryegrass silage and maize silage as feed for cows]. Informatore Agrario 60(32):37–44.
30 Chalupa, W. and Sniffen, C.J. 2000. Balancing rations for milk components. Asian-Australasian Journal of Animal Sciences 13(Suppl.):388–396.
31 Khan, N.A., Cone, J.W., Fievez, V., and Hendriks, W.H. 2012. Causes of variation in fatty acid content and composition in grass and maize silages. Animal Feed Science and Technology 174(1–2):36–45.
32 Bauman, D.E., Lock, A.L., Corl, B.A., Ip, C., Salter, A.M., and Parodi, P.W. 2006. Milk fatty acids and human health: Potential role of conjugated linoleic acids and trans fatty acids. In K. Sejrsen, T. Hvelplund, and M.O. Nielsen (eds). Ruminant Physiology—Digestion, Metabolism and Impact of Nutrition on Gene Expression, Immunology and Stress. Wageningen Academic Publishers, Netherlands. p. 529–561.
33 Fall, N. and Emanuelson, U. 2011. Fatty acid content, vitamins and selenium in bulk tank milk from organic and conventional Swedish dairy herds during the indoor season. Journal of Dairy Research 78(3):287–292.
34 DACH. 2008. Referenzwerte für die Nährstoffzufuhr [Reference Values for the Nutrient Supply]. Umschau Braus, Frankfurt am Main, Deutschland.
35 Chilliard, Y., Ferlay, A., Mansbridge, R.M., and Doreau, M. 2000. Ruminant milk fat plasticity: Nutritional control of saturated, polyunsaturated, trans and conjugated fatty acids. Annales de Zootechnie 49(3):181–205.
36 Hof, G., Vervoorn, M.D., Lenaers, P.J., and Tamminga, S. 1997. Milk urea nitrogen as a tool to monitor the protein nutrition of dairy cows. Journal of Dairy Science 80 (12):3333–3340.
37 Nousiainen, J., Shingfield, K.J., and Huhtanen, P. 2004. Evaluation of milk urea nitrogen as a diagnostic of protein feeding. Journal of Dairy Science 87(2):386–398.
38 National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th ed. National Academy Press, Washington, DC, USA.
39 Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. 2nd ed. Cornell University Press, Ithaca, New York, USA.
40 Velik, M., Baumung, R., Zollitsch, W., and Knaus, W.F. 2007. Effects of partial substitution of concentrates by maize silage on performance and feed efficiency in organic dairy cow rations. Journal of the Science of Food and Agriculture 87(14):2657–2664.
41 Steinshamn, H. and Thuen, E. 2008. White or red clover-grass silage in organic dairy milk production: Grassland productivity and milk production responses with different levels of concentrate. Livestock Science 119(1–3):202–215.
42 Velik, M., Baumung, R., and Knaus, W.F. 2007. Maize silage as an energy supplement in organic dairy cow rations. Renewable Agriculture and Food Systems 23(2):155–160.
43 Chase, L.E. 2003. Nitrogen utilization in dairy cows—what are the limits of efficiency? In Proceedings of the Cornell Nutrition Conference for Feed Manufacturers, Syracuse, New York, October 21–23, 2003. Cornell University Press, Ithaca, NY, USA. p. 233–245.
44 Powell, J.M., Gourley, C.J.P., Rotz, C.A., and Weaver, D.M. 2010. Nitrogen use efficiency: A potential performance indicator and policy tool for dairy farms. Environmental Science and Policy 13(3):217–228.
45 Givens, D.I. and Rulquin, H. 2004. Utilisation by ruminants of nitrogen compounds in silage-based diets. Animal Feed Science and Technology 114(1–4):1–18.

CAMBRIDGE JOURNALS

The Journal of Agricultural Science



Senior Editor (Animal papers)
Julian Wiseman, *University of Nottingham, UK*
Senior Editor (Crops & Soils papers)
Paul Bilsborrow, *Newcastle University, UK*

The Journal of Agricultural Science publishes papers concerned with the advance of agriculture and the use of land resources throughout the world. It publishes original scientific work related to strategic and applied studies in all aspects of agricultural science, including: crop and animal physiology, modelling of crop and animal systems, the scientific underpinning of agronomy and husbandry, engineering solutions, decision support systems, land use, environmental impacts of agriculture and forestry, impacts of climate change, rural biodiversity, experimental design and statistical analysis, the application of new analytical and study methods (including molecular studies). The journal also publishes book reviews and letters.

The Journal of Agricultural Science is available online at:
http://journals.cambridge.org/ags

To subscribe contact Customer Services

Americas:
Phone +1 (845) 353 7500
Fax +1 (845) 353 4141
Email
subscriptions_newyork@cambridge.org

Rest of world:
Phone +44 (0)1223 326070
Fax +44 (0)1223 325150
Email journals@cambridge.org

Submit your research online
http://mc.manuscriptcentral.com/jagrisci

Free email alerts
Keep up-to-date with new material – sign up at
journals.cambridge.org/ags-alerts

For free online content visit:
http://journals.cambridge.org/ags

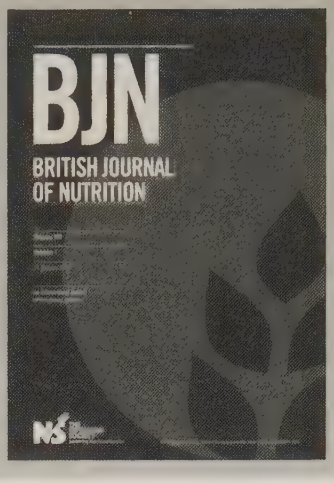
CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE JOURNALS

BJN

BRITISH JOURNAL OF NUTRITION

Editor-in-Chief
G C Burdge, *University of Southampton, UK*



British Journal of Nutrition is a leading international peer-reviewed journal covering research on human and clinical nutrition, animal nutrition and basic science as applied to nutrition. The journal recognises the multi-disciplinary nature of nutritional science and includes material from all of the specialities involved in nutrition research, including molecular and cell biology, and the emerging area of nutritional genomics.

Impact Factor 3.302

Ranked **18/76**
Nutrition and Dietics

2012 Journal Citation Reports®
Thomson Reuters

journals.cambridge.org/bjn

Submit your article online
bjn.msubmit.net

Register for free content alerts
journals.cambridge.org/bjn-alerts

To subscribe contact
Customer Services

Cambridge:
Phone +44 (0)1223 326070
Fax +44 (0)1223 325150
journals@cambridge.org

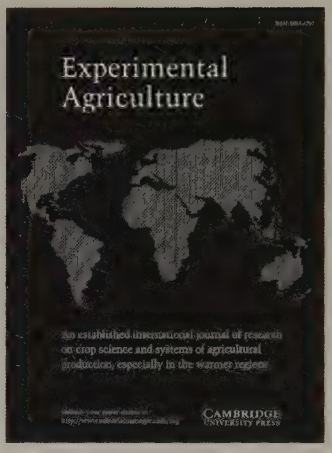
New York:
Phone +1 (845) 353 7500
Fax +1 (845) 353 4141
subscriptions_newyork@cambridge.org

THE NUTRITION SOCIETY
Advancing Nutritional Science

CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE JOURNALS

Experimental Agriculture



Editor
Dave Harris, *ICRISAT, Kenya*

Experimental Agriculture publishes the results of original research from any source on the agronomy of field, plantation and herbage crops grown for human or animal food; for industrial purposes; and on systems of agricultural production, particularly in the warmer regions of the world. It is especially concerned with experimental work designed to explain agronomic results in biological and environmental terms. The journal publishes accounts of new experimental techniques, new methods of crop production and discusses problems in countries where production is developing rapidly. There are regular book reviews and occasional, often invited, reviews of research.

Experimental Agriculture
is available online at:
http://journals.cambridge.org/eag

To subscribe contact Customer Services

Americas:
Phone +1 (845) 353 7500
Fax +1 (845) 353 4141
Email
subscriptions_newyork@cambridge.org

Rest of world:
Phone +44 (0)1223 326070
Fax +44 (0)1223 325150
Email journals@cambridge.org

For free online content visit:
http://journals.cambridge.org/eagsample

Price Information
is available at:
http://journals.cambridge.org/eag

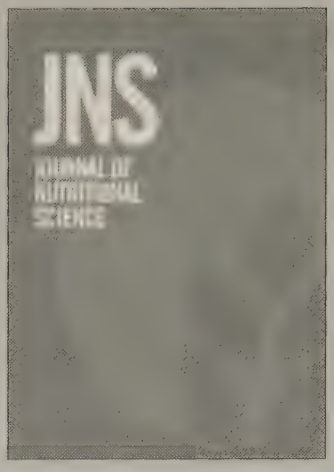
Free email alerts
Keep up-to-date with new content
http://journals.cambridge.org/eag-alerts

CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE JOURNALS

JNS

JOURNAL OF NUTRITIONAL SCIENCE



Editor-in-Chief
G C Burdge, *University of Southampton, UK*

Cambridge Open

Journal of Nutritional Science encompasses the full spectrum of nutritional science including public health nutrition, epidemiology, dietary surveys, nutritional requirements, metabolic studies, body composition, energetics, appetite, obesity, ageing, endocrinology, immunology, neuroscience, microbiology, genetics and molecular and cell biology. The Nutrition Society fully engages with the Open Access model of publishing.

journals.cambridge.org/jns

Submit your article online
jnutsci.msubmit.net

Register for free content alerts
journals.cambridge.org/jns-alerts

THE NUTRITION SOCIETY
Advancing Nutritional Science

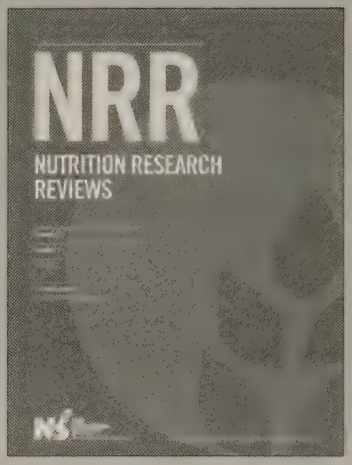
CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE JOURNALS

NRR

NUTRITION RESEARCH REVIEWS

Editor-in-Chief
Jayne V. Woodside, *Queen's University, Belfast, UK*



Nutrition Research Reviews offers a comprehensive overview of nutritional science today. By distilling the latest research and linking it to established practice, the journal consistently delivers the widest range of in-depth articles in the field of nutritional science and has done so for the past twenty-one years. It presents up-to-date, concise and critical reviews of key topics in nutrition science, advancing new concepts and hypotheses that encourage the exchange of fundamental ideas on nutritional well-being in both humans and animals.

Impact Factor 5.5

Ranked **4/76**
Nutrition and Dietics

2012 Journal Citation Reports®
Thomson Reuters

Submit your article online
nrr.msubmit.net

Register for free content alerts
journals.cambridge.org/nrr-alerts

To subscribe contact
Customer Services

Cambridge:
Phone +44 (0)1223 326070
Fax +44 (0)1223 325150
journals@cambridge.org

New York:
Phone +1 (845) 353 7500
Fax +1 (845) 353 4141
subscriptions_newyork@cambridge.org

THE NUTRITION SOCIETY
Advancing Nutritional Science

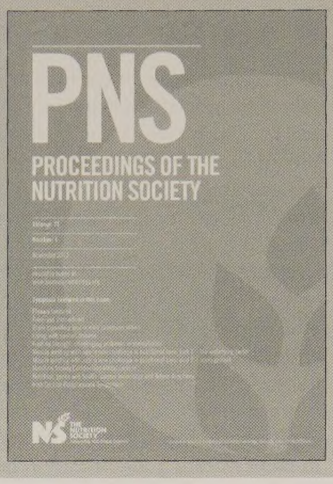
CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE JOURNALS

PNS

PROCEEDINGS OF THE NUTRITION SOCIETY

Editor-in-Chief
Maria O'Sullivan
Trinity College Medical Centre, Republic of Ireland



Proceedings of the Nutrition Society publishes papers and abstracts presented by members and invited speakers at the scientific meetings of The Nutrition Society. The journal provides an invaluable record of the scientific research currently being undertaken, contributing to 'the scientific study of nutrition and its application to the maintenance of human and animal health.'

Impact Factor 3.674

Ranked **14/76**
Nutrition and Dietics

2012 Journal Citation Reports®
Thomson Reuters

journals.cambridge.org/pns

Register for free content alerts
journals.cambridge.org/pns-alerts

To subscribe contact
Customer Services

Cambridge:
Phone +44 (0)1223 326070
Fax +44 (0)1223 325150
journals@cambridge.org

New York:
Phone +1 (845) 353 7500
Fax +1 (845) 353 4141
subscriptions_newyork@cambridge.org

THE NUTRITION SOCIETY
Advancing Nutritional Science

CAMBRIDGE UNIVERSITY PRESS

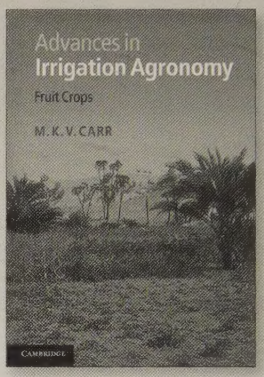
CAMBRIDGE

eBooks Available!

ADVANCES IN IRRIGATION AGRONOMY

Fruit Crops

M. K. V. Carr



As global pressure on water resources intensifies, it is essential that scientists understand the role that water plays in the development of crops and how such knowledge can be applied to improve water productivity. Linking crop physiology, agronomy and irrigation practices, this book focuses on eleven key fruit crops upon which millions of people in the tropics and subtropics depend for their livelihoods (avocado, cashew, Citrus spp., date palm, lychee, macadamia, mango, olive, papaya, passion fruit and pineapple). Each chapter reviews international irrigation research on an individual fruit crop, identifying opportunities for improving the effectiveness of water allocation and encouraging readers to link scientific knowledge with practical applications. Clearly written and well illustrated, this is an ideal resource for engineers, agronomists and researchers concerned with how the productivity of irrigated agriculture can be improved, in the context of climate change, and the need for growers to demonstrate good irrigation practices.

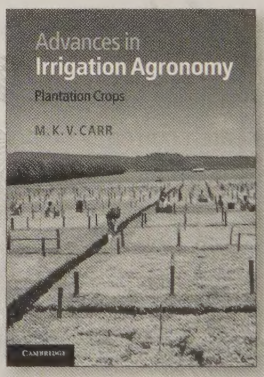
$115 / £70: Hardback: 978-1-107-03735-9: 350 pp.

ADVANCES IN IRRIGATION AGRONOMY

Plantation Crops

M. K. V. Carr

With contributions by Rob Lockwood *and* Jerry Knox



Praise for the book:

"This book will become a major source of reference for those working on irrigated plantation crops, and it can be thoroughly recommended to readers." – *Agriculture for Development*

"An excellent publication both in terms of content and presentation... No doubt [it] will be a great help for all those researchers and practitioners involved in improving water use productivity of an important but so far somewhat neglected group of crops." – Martin Smith, *Experimental Agriculture*

"Mike Carr is to be congratulated on producing a rigorous but readable assessment of the state of knowledge of the water needs and irrigation agronomy of 10 major plantation crops. He has used his 45 years of experience and knowledge as researcher, tutor and editor to produce a valuable reference book for anyone studying irrigation agronomy or planning to conduct research on plantation crops. For the busy reader he has produced a helpful summary at the end of each section – for those needing more information the conclusions are supported by over 800 references. In a final chapter he summarizes the similarities and differences in water needs and irrigation between the 9 crops. He concludes with a plea for better reporting of research and valuably identifies the gaps in knowledge and where future research is needed." – Andrew Bennett CMG, President of the Tropical Agriculture Association (TAA), UK

$117 / £69: Hardback: 978-1-107-01247-9: 360 pp.

Prices subject to change.

www.cambridge.org/lifesciences
800.872.7423 / +44 (0)1223 325781
@cambUP_lifesci

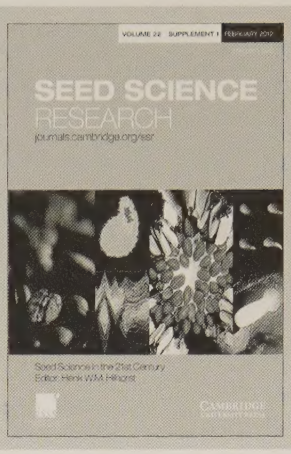
CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE JOURNALS

Seed Science Research

The official journal of the International Society for Seed Science (ISSS)

Editor-in-Chief
H.W.M. Hilhorst, Wageningen University, The Netherlands



Seed Science Research is an international journal publishing original and opinon papers, as well as reviews. The Journal deals primarily with the fundamentals of seed research with emphasis on the physiology, biochemistry, molecular biology and ecology of seed development, dormancy and germination.

The importance of seeds to propagation, food, biofuel and biodiversity is of increasing interest and therefore submissions on seed genetics, seed biotechnology, seed treatment and seedling establishment are especially encouraged if they are novel and 'seed driven'.

For free online content visit:
http://journals.cambridge.org/ssr_sample

Free email alerts
Keep up-to-date with new content
http://journals.cambridge.org/ssr-alerts

Seed Science Research
is available online at:
http://journals.cambridge.org/ssr

To subscribe contact Customer Services

Americas:
Phone +1 (845) 353 7500
Fax +1 (845) 353 4141
Email
subscriptions_newyork@cambridge.org

Rest of world:
Phone +44 (0)1223 326070
Fax +44 (0)1223 325150
Email journals@cambridge.org

Price Information
is available at:
http://journals.cambridge.org/ssr

CAMBRIDGE UNIVERSITY PRESS

IF
BSM
REVIEW

VOLUME 29 ISSUE 4 DECEMBER 2014

Renewable Agriculture and Food Systems

journals.cambridge.org/raf

RESEARCH PAPERS

Certified quality systems and farming practices in olive growing: The case of integrated production in Andalusia
Ascensión Hinojosa-Rodríguez, Carlos Parra-López, Carmen Carmona-Torres, Samir Sayadi and Rosa Gallardo-Cobos 291

Comparative carbon footprint assessment of winter lettuce production in two climatic zones for Midwestern market
Rachel Plawecki, Rich Pirog, Adam Montri and Michael W. Hamm 310

Mental models of organic weed management: Comparison of New England US farmer and expert models
Randa Jabbour, Sarah Zwickle, Eric R. Gallandt, Katherine E. McPhee, Robyn S. Wilson and Doug Doohan 319

Net returns and risk for cover crop use in Alabama tomato production
Leah M. Duzy, Ted S. Kornecki, Kipling S. Balkcom and Francisco J. Arriaga 334

A multi-criteria assessment of the production and marketing systems of local mountain food
Jernej Prišenk, Črtomir Rozman, Karmen Pažek, Jernej Turk, Zarja Bohak and Andreja Borec 345

Economic analysis of private and public benefits of corn, switchgrass and mixed grass systems in Eastern South Dakota
Nelly Bourlion, Larry Janssen and Michael Miller 355

Assessment of on-farm conservation of dryland agrobiodiversity and its impact on rural livelihoods in the Fertile Crescent
Ahmed Mazid, Kamil Shideed and Ahmed Amri 366

Maize silage and Italian ryegrass silage as high-energy forages in organic dairy cow diets: Differences in feed intake, milk yield and quality, and nitrogen efficiency
L. Baldinger, W. Zollitsch and W.F. Knaus 378

Submit your paper online
http://www.edmgr.com/rafs

Register online to receive free table-of-contents alerts
http://journals.cambridge.org/raf-alerts

Cambridge Journals Online
For further information about this journal please go to the journal web site at:
journals.cambridge.org/raf

FSC www.fsc.org
MIX
Paper from responsible sources
FSC® C013436

CAMBRIDGE UNIVERSITY PRESS